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REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF TH--ETC(U)
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U.S. ARMY ENGINEER DISTRICT PHILADELPHIA
U.S. ARMY ENGINEER DIV. • NORTH ATLANTIC

DELAWARE RIVER BASIN REPORT

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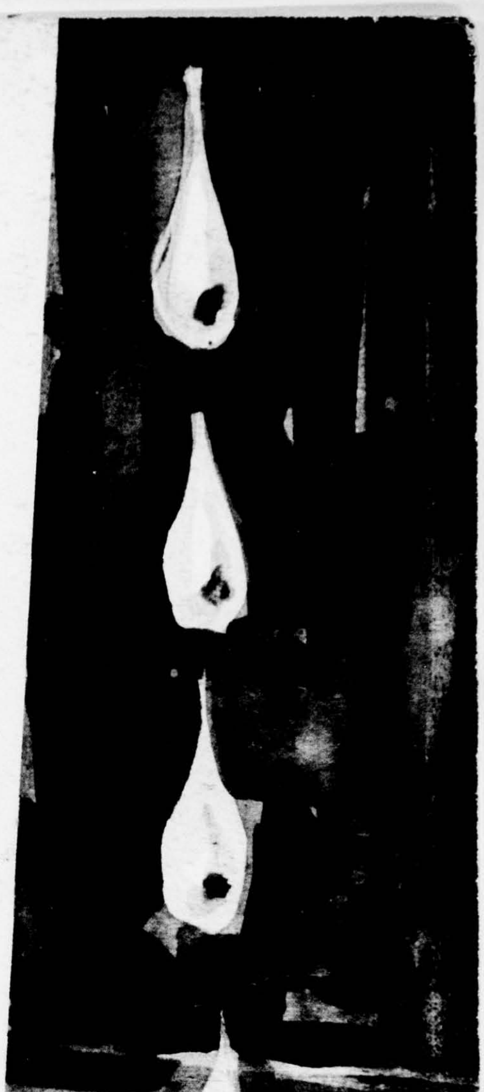
DEC. 1960

VOL. VI

APPENDIX L. INSECTS OF PUBLIC HEALTH IMPORTANCE IN THE DELAWARE BASIN and

APPENDIX M. HYDROLOGY



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REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN.

Volume VI.

APPENDIX L and M.

INSECTS OF PUBLIC HEALTH IMPORTANCE

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June 1957
for
U. S. ARMY ENGINEER DISTRICT, PHILADELPHIA
CORPS OF ENGINEERS
PHILADELPHIA, PA.

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PREFACE

This report, which pertains to insect problems associated with the development of water and related land resources, was prepared by the Public Health Service. The following agencies rendered valuable assistance in providing basic information:

<u>Delaware</u>

State Board of Health, Dover
Delaware Agricultural Experiment Station, Newark
State Board of Agriculture, Dover
Mosquito Control Division, State Highway Department, Lewes

<u>New Jersey</u>

State Department of Health, Trenton
New Jersey Agricultural Experiment Station, New Brunswick
Morris County Mosquito Extermination Commission, Morris Plains

<u>New York</u>

State Department of Health, Albany
New York State Science Service, Albany
Suffolk County Mosquito Control Commission, Yaphank

<u>Pennsylvania</u>

State Department of Health, Harrisburg
Delaware County Mosquito Extermination Commission, Media

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INTRODUCTION

Authority for Report

1. The Corps of Engineers has been directed by the Congress to prepare a report presenting the best plan for the conservation, control, and use of the water resources of the Delaware River basin (fig. 1). The plan will be based on a comprehensive survey and study of the matter. The District Engineer, Army Engineer District, Philadelphia, will prepare the plan and basic report for the Corps in cooperation with various Federal, State, and interstate agencies, also the 2 major cities concerned.

Objectives

2. This report has been prepared to provide information on the present status of insect-borne diseases and insect vectors and their control; to determine the influence that resource developments may have upon insect problems; and to draw conclusions and make recommendations for safeguarding the public health through the control of insect problems.*

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* The term insect as used here includes ticks and mites.

Vector is here defined as an insect or other arthropod that transmits disease or causes annoyance and irritation to man.

PRESENT STATUS OF INSECTS ADVERSE TO PUBLIC HEALTH

General Statement

3. Insects of public health importance are considered in 2 groups: (a) those capable of carrying and transmitting specific disease micro-organisms, and (b) those species that cause extreme physical annoyance, mental anguish, and allergic manifestations.

4. Vectors of disease include the following species: Anopheles quadrimaculatus (malaria), Culiseta melanura (eastern equine encephalitis), and Dermacentor variabilis (Rocky Mountain spotted fever).

5. The following groups of insects are important because of their annoyance to humans in the region: (a) Salt-marsh mosquitoes (Aedes sollicitans, Aedes cantator, Culex salinarius, Anopheles bradleyi); (b) fresh-water mosquitoes (Aedes vexans, Culex pipiens, Mansonia perturbans, Aedes canadensis, Anopheles quadrimaculatus); (c) greenhead flies (Tabanus nigrovittatus); (d) deer flies (Chrysops species); (e) biting gnats (Culicoides species); (f) black flies (Simuliidae); (g) stable flies (Stomoxys calcitrans); (h) ticks (Dermacentor variabilis and Amblyomma americanum); and (i) chiggers (Eutrombicula alfreddugesi).

6. The nature and importance of public health problems involving insects vary considerably between the northern mountainous and hilly areas and the southern coastal and tidewater areas of the Delaware River basin. In general, insect problems of the upper basin area, i.e. north of Trenton, New Jersey, are localized and minor. In this area, salt-marsh mosquitoes, greenhead flies, ticks, and chiggers are virtually absent. Black flies, which are so pestiferous in the Adirondacks are only occasionally a problem in the Catskills (the headwaters of the Delaware River), the Poconos, and other mountains of the upper portion of the watershed. Minor problems include fresh-water mosquitoes (woodland pool, floodwater, domestic, and aquatic-plant types), deer flies, and biting gnats.

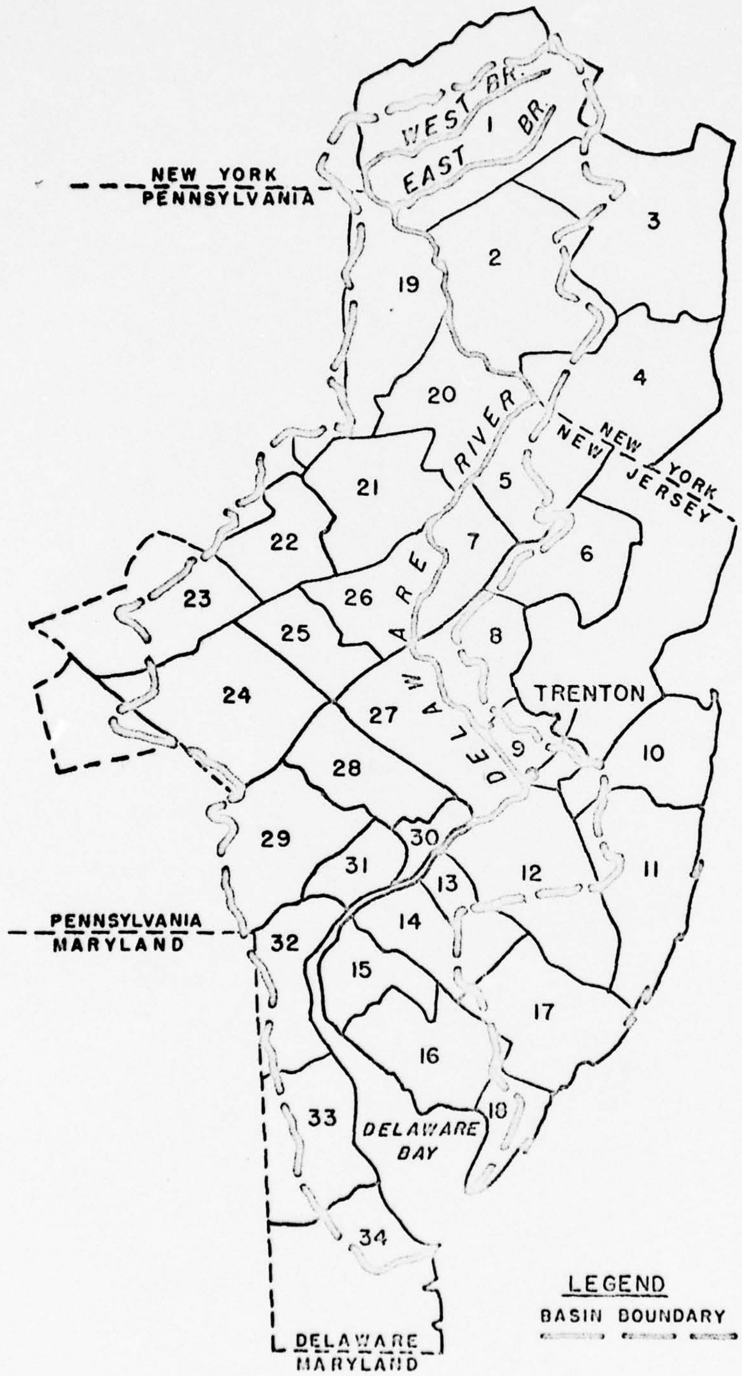
7. The lower Delaware basin, with its extensive tidal marshlands, is notorious for salt-marsh and fresh-water mosquito problems. Important problems in localized areas are caused by greenhead flies, deer flies, biting gnats, and ticks. Stable flies and chiggers are of relatively minor importance.

Insect-Borne Diseases

Malaria

8. Historically, malaria was considered to be an endemic disease in the Delaware River basin during the latter part of the 19th century. Although many cases of this protozoan disease have been reported from the 4-State area since 1930 (table 1), the majority of these cases represent infections acquired outside continental United States. Upsurges in

Fig. 1 COUNTIES IN THE DELAWARE RIVER BASIN



COUNTIES

NEW YORK
1. DELAWARE
2. SULLIVAN
3. GREENE
4. ORANGE

NEW JERSEY
5. SUSSEX
6. MORRIS
7. WARREN
8. HUNTERDON
9. MERCER
10. MONMOUTH
11. OCEAN
12. BURLINGTON
13. CAMDEN
14. GLOUCESTER
15. SALEM
16. CUMBERLAND
17. ATLANTIC
18. CAPE MAY

PENNSYLVANIA
19. WAYNE
20. PIKE
21. MONROE
22. CARBON
23. SCHUYLKILL
24. BERKS
25. LEHIGH
26. NORTHAMPTON
27. BUCKS
28. MONTGOMERY
29. CHESTER
30. PHILADELPHIA
31. DELAWARE

DELAWARE
32. NEW CASTLE
33. KENT
34. SUSSEX

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ATLANTA, GA. JULY, 1957

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reporting as a concomitant of World War II and the Korean conflict are very evident. No primary indigenous cases have been reported in the area during recent years. It is concluded that malaria presently constitutes only a minor public health threat in the Delaware basin.

9. The malaria vector (Anopheles quadrimaculatus) is a common mosquito in northern Delaware and southern New Jersey. The highest concentrations of this species have been found in New Castle County, Delaware (Delaware City) and Salem County, New Jersey. Anopheles quadrimaculatus mosquitoes usually breed in permanent-water habitats, such as ponds, swamps, sloughs, and shallow margins and backwater areas of reservoirs. The presence of vegetation or flotage in the water enhances malaria mosquito production.

Encephalitis

10. Of the 3 principal types of mosquito-borne encephalitis ("sleeping sickness" or "brain fever") found in the United States, only the virus of eastern equine encephalitis (EEE) is known to have caused outbreaks of disease in the region. These outbreaks have involved horses, captive pheasants and human beings.

11 a. Definite knowledge of EEE dates back to 1933, when a horse epizootic occurred in coastal and tidewater areas of New Jersey and Delaware. This disease has not caused large outbreaks among humans or horses in eastern United States, but it is highly virulent. Mortality rates average 60 percent for humans and 90 percent for horses. Of 48 reported horse cases in New Jersey in 1956, 46 died. Furthermore, individuals who survive frequently suffer from permanent brain damage. This is exemplified by a recent (1956) human case in Sussex County, Delaware - the first confirmed human case in the basin area. Although this 39-year old male survived, he is now in a hopeless vegetative state.

11 b. An outbreak of eastern equine encephalitis in New Jersey in September 1959, with 32 reported human cases and 22 fatalities, was the second greatest recorded epidemic of this disease in the United States. The cases and deaths were reported from 5 counties in the southern half of the State (Ocean, Atlantic, Cape May, Cumberland, and Burlington Counties). The patients lived in rural wooded areas adjacent to both salt-marshes and fresh-water swamps inland from the Atlantic Coast where mosquito populations were high during the summer months.

12. Reported cases of encephalitis are given in tables 2 and 3. It will be noted that EEE has been an important disease of horses in Delaware and New Jersey, but it has been virtually absent from New York and Pennsylvania. It is noteworthy that the greatest number of cases were reported in 1956. Data for 1956 show that the largest

Table 1. Reported Cases of Malaria

Year	Delaware	New Jersey	New York	Pennsylvania
1930	0	14	105	10
1931	0	7	59	18
1932	3	6	46	12
1933	0	9	77	13
1934	3	19	103	28
1935	1	155	77	17
1936	18	38	97	23
1937	2	27	110	17
1938	6	16	122	15
1939	0	12	123	10
1940	0	15	132	15
1941	1	13	80	8
1942	0	20	104	7
1943	4	20	124	4
1944	15	826	553	123
1945	47	1,412	1,315	608
1946	12	931	2,024	138
1947	0	99	102	0
1948	0	36	35	0
1949	0	26	26	3
1950	0	11	10	4
1951	3	371	100	5
1952	0	191	184	1
1953	0	22	22	5
1954	0	27	10	3
1955	0	8	12	0
1956*	0	3	0	0
Total	115	4,334	5,752	1,087

* Tentative figures.

Source: National Office of Vital Statistics, U. S. Public Health Service.

Table 2. Reported Horse Cases of Encephalitis

Year	Delaware	New Jersey	New York	Pennsylvania
1935	0	2	4	0
1936	*	0	0	0
1937	0	10	0	0
1938	1	13	0	0
1939	7	35	1	0
1940	0	0	4	0
1941	1	0	0	0
1942	8	0	0	0
1943	1	0	1	0
1944	0	1	0	0
1945	12	26	0	0
1946	15	19	0	0
1947	1	7	0	0
1948	7	9	0	0
1949	3	3	0	0
1950	3	1	0	0
1951	0	1	0	0
1952	1	5	0	0
1953	1	0	0	1
1954	0	0	0	0
1955	11	2	0	0
1956	25	48	0	0
Total	97	182	10	1

Source: Annual reports of U. S. Department of Agriculture.

* Some cases reported but no actual count.

Table 3. Reported Outbreaks* of Encephalitis Among Captive Pheasants

Year	Delaware	New Jersey	New York	Pennsylvania
1938	0	1	0	0
1939	0	3	0	0
1940	0	1	0	0
1941	0	0	0	0
1942	0	0	0	0
1943	0	1	0	0
1944	0	2	0	0
1945	0	3	0	0
1946	0	2	0	0
1947	0	0	0	0
1948	0	1	0	0
1949	0	0	0	0
1950	0	0	0	0
1951	0	5	0	1
1952	0	4	1	0
1953	0	4	0	0
1954	0	0	0	0
1955	0	1	0	0
1956	0	19	0	0
Total	0	47	1	1

* The number of cases and deaths in each outbreak varied from less than 100 to over 1,000 birds.

Source: 1938 - 1953 - Series of 7 published papers by F. R. Beaudette et al.

1955-- 1956 - Surveillance Section, Epidemiology Branch, Communicable Disease Center, U. S. Public Health Service.

number of horse cases were reported from Sussex County, Delaware, and Gloucester County, New Jersey.

13. Definite knowledge regarding the natural history of eastern equine encephalitis virus is lacking, but present evidence indicates that wild and domestic birds, particularly nestlings, are the principal reservoirs of infection, and mosquitoes the vectors. The basic infection chain is normally limited to birds and mosquitoes, with humans and horses as accidental entries.

14. Recent studies on vectors of eastern equine encephalitis have implicated the mosquito Culiseta melanura as the primary vector for maintaining the basic infection chain in nature (bird-mosquito-bird). It is not known, however, whether C. melanura is responsible for human and horse outbreaks of EEE, or whether some other mosquitoes, such as Aedes, Psorophora, or Mansonia are the vectors.

15. Culiseta melanura was formerly considered to be a relatively rare mosquito in the basin, but recent studies in New Jersey show that its distribution is stateside. It is very selective in its breeding places, however, and thus tends to be a localized mosquito. Preferred habitats are secluded permanent-water areas that are dark (shaded), cool, and acid. Principal habitats in New Jersey include sphagnum bogs in the north, pigeon swamps with dense cover in the center of the State, and cedar-type swamps in the southeast. Highest populations of this mosquito are found in late summer and early fall, a period corresponding with encephalitis outbreaks. C. melanura feeds extensively upon birds and occasionally upon mammals. Whether or not it feeds on humans under natural conditions is conjectural.

16. Of all the insect-borne diseases in the Delaware basin, encephalitis has the highest potential. At present there is no known therapeutic treatment, and human immunization is not available; commercial vaccines are available for horses and pheasants. On the basis of current knowledge concerning the disease, the only feasible approach to the control of encephalitis is a program of prevention--mosquito control for the community and protection against mosquito bites for the individual.

Rocky Mountain Spotted Fever

17. Each year the number of reported cases of Rocky Mountain spotted fever for the 4-State area averages about 4 for Delaware, 11 for New Jersey, 10 for New York, and 8 for Pennsylvania (table 4). Most of the cases have been reported from areas where the American dog tick (Dermacentor variabilis) is common, viz, southeastern Pennsylvania, all of Delaware, southern and central New Jersey, and Long Island, New York. In the East, the majority of cases have been reported during the months of May and June, and the incidence has been

Table 4. Reported Cases of Rocky Mountain Spotted Fever

Year	Delaware	New Jersey	New York*	Pennsylvania
1931	1	1	0	0
1932	0	3	0	0
1933	3	0	3	2
1934	3	0	4	1
1935	0	1	1	3
1936	3	4	1	4
1937	1	8	2	2
1938	3	16	6	2
1939	5	28	12	16
1940	6	12	0	8
1941	6	5	9	10
1942	1	14	9	13
1943	15	16	19	11
1944	4	19	23	7
1945	5	15	17	7
1946	16	17	18	16
1947	5	26	23	16
1948	5	12	21	15
1949	4	16	10	17
1950	1	11	12	12
1951	2	10	9	7
1952	1	10	11	4
1953	0	8	21	6
1954	1	6	12	11
1955	3	10	9	7
Total	94	268	252	197

* Cases reported principally from Long Island.

Source: National Office of Vital Statistics, U. S. Public Health Service.

highest among vacationists and picnickers, particularly among women and children.

18. Preventive measures for this rickettsial disease include avoiding tick-infested areas (usually wooded or brushy areas and grassy fields), using insect repellents (diethyltoluamide), and vaccination. In recreational areas, tick populations may be reduced by cutting or herbicidal treatment of brush and weeds, mowing grass, and applying insecticides (DDT) along paths and roadsides.

19. Specific treatment for Rocky Mountain spotted fever is available. The use of appropriate antibiotics has reduced the fatality rate from 20 percent to 6 or 7 percent.

Insect Species Causing Extreme Physical Annoyance, Mental Anguish, and Allergic Manifestations

Salt-Marsh Mosquitoes

20. The most formidable biting insects in Delaware and southern New Jersey are the so-called salt-marsh mosquitoes, particularly *Aedes sollicitans*. Other salt-marsh or brackish-water species include *Aedes cantator*, *Culex salinarius*, and *Anopheles bradleyi*.

21. At times *A. sollicitans* (the "New Jersey mosquito") occurs in such overwhelming numbers that outdoor activities during the day or night are practically impossible. This species is especially troublesome in Kent and Sussex Counties, Delaware, and in Salem, Cumberland, and Cape May Counties, New Jersey. The breeding of this species is limited mostly to salt marshes or other coastal locations. The most important salt-marsh breeding areas are those which are inundated infrequently. The inundation may result from unusually high tides or heavy rains, such as those accompanying the 3 hurricanes in 1955. Significant breeding places of *A. sollicitans* are frequently associated with salt-meadow cord grass (*Spartina patens*), since this plant tends to grow in coastal areas not subject to the daily tides. In many areas large broods of this mosquito occur about 3 times per year. This species is noted for flying long distances; 8 miles is sometimes given as the "effective" flight range, but under certain conditions it may fly 20 miles or farther.

22. *Aedes cantator* (the northeastern salt-marsh mosquito) is a tidal-marsh inhabitant, but it prefers the less brackish situations; hence, it is more common in the upper reaches of the Delaware Bay and lower Delaware River. The heaviest production occurs on that part of the tidal marsh immediately adjacent to the uplands. This important man-biting mosquito is usually the most common species in the spring.

23. Culex salinarius (the brackish- and fresh-water Culex) is a common species in the lower Delaware basin. In New Jersey, it is uncommon north of Burlington County. This species breeds throughout the summer in both brackish and fresh-water habitats. In salt-marsh areas it prefers salt-meadow cord grass (Spartina patens), and in fresh water it is frequently associated with cattail, reed (Phragmites), and millet. This mosquito bites readily outdoors after dark.

24. Anopheles bradleyi is very selective for salt-marsh areas. This night-biting mosquito, which has a relatively short flight range, does not create too much of a nuisance problem because its populations do not build up until late fall.

Fresh-Water Mosquitoes

25. For the basin as a whole, fresh-water mosquito problems actually exceed those described in the preceding section of this report. The most significant of these problems are caused by house mosquitoes, floodwater mosquitoes, aquatic-plant mosquitoes, malaria mosquitoes, and fresh-water marsh Culex mosquitoes.

26. Culex pipiens (northern house mosquito) is widely distributed throughout the Delaware basin, particularly in urban areas. This so-called domestic mosquito breeds profusely in polluted water areas, including both organic (sewage) and inorganic materials, such as effluent from industrial plants. Other significant sources are street catch basins and clogged drainage ditches. Because of the high industrialization and high urbanization in the Trenton-Philadelphia- and Wilmington areas, the C. pipiens problem is increasing each year. This non-agressive mosquito is annoying principally indoors after dark. C. pipiens is recognized as a vector of St. Louis encephalitis in central United States, and thus is a potential disease vector in the basin.

27. Aedes vexans (floodwater or rain pool mosquito) is especially troublesome in the 4-State area because of its general abundance, its aggressive biting habits during the day and night, its attraction to lights in urban areas, and its long flight range of from 5 to 10 miles. This species is presenting a major problem in the Wilmington area of New Castle County, Delaware, where extensive acreages of rough, grassland breeding areas are contiguous to newly developed unincorporated communities. A. vexans is one of the most important mosquitoes in the basin from the standpoint of annoyance to man.

28. Mansonia perturbans (aquatic-plant mosquito) is basin-wide in distribution, but occurs in localized situations. This is correlated with the restriction of its breeding to water areas containing heavy emergent vegetation, such as cattail. The larvae and pupae of Mansonia mosquitoes are unique in that they are attached to the roots

and submerged stems of plants, from which they obtain their air supply. M. perturbans bites at night and is an important pest in communities near permanent shallow-water areas infested with cattail and other types of emergent vegetation.

29. Aedes canadensis (woodland pool mosquito) is found in wooded areas throughout the basin. A favorite larval source is pools containing leaves. This mosquito tends to be an early season nuisance, with sporadic late season flare-ups.

30. Anopheles quadrimaculatus (malaria mosquito) and Culex salinarius (fresh-water marsh Culex). Refer to paragraphs 9 and 23.

Miscellaneous Biting Flies, Ticks, and Chiggers

31. Horse flies, deer flies, biting gnats, black flies, and ticks cause considerable annoyance in the Delaware basin. Minor problems are caused by stable flies and chiggers.

32. Horse flies (greenhead flies). Species of horse flies commonly called greenhead flies (Tabanus nigrovittatus) are important pests of man along the Delaware Bay shore, extending up to Delaware County, Pennsylvania, and Salem County, New Jersey. In general, the number of greenhead flies is related to the amount of salt-marsh cord grass, Spartina alterniflora, in the immediate vicinity. The seasonal distribution of the adults extends from late June to September, with peak populations in July. Greenhead flies attack humans readily and are of particular concern in resort areas.

33. Deer Flies (Chrysops species) are especially troublesome along the Delaware Bay shore. Localized deerfly problems occur throughout the basin. Breeding grounds for deer flies include salt marshes, fresh-water marshes, and the margins of ponds and streams. The larvae of certain species occur along with greenhead larvae, i. e. associated with salt-marsh cord grass. Frequently, the adult flies do not remain on the marsh, but move to adjacent uplands, especially into wooded areas, where they constitute a real daytime pest. Deer flies are a major problem in park and recreational areas throughout the summer months. Some of the most annoying species to humans in the basin are: Chrysops atlantica, C. callida, C. flavida, C. fuliginosa, C. obsoleta, and C. vittata.

34. Biting gnats (Culicoides species). The principal problem area for biting gnats, or "punkies," "sand flies," "no-see-ems," is salt marshes along the Delaware Bay shore. One of the most abundant of the man-biting species is Culicoides canithorax. The greatest nuisance is caused during the months of June and July.

35. Ticks. The American dog tick (Dermacentor variabilis) is locally abundant in the lower two-thirds of New Jersey, the 3 counties of Delaware, and southeastern Pennsylvania. The worst tick problem in New Jersey is in Gloucester and Salem counties. One of the favorite places for ticks is the abandoned farm, where small rodents have become abundant. The dog tick is a 3-host tick: Larvae and nymphs are frequently found on meadow mice and white-footed mice, while adult ticks commonly attach themselves to racoons, foxes, rabbits, dogs, and humans. May and June are the principal tick months.

36. The American dog tick is of public health significance in the basin because it transmits Rocky Mountain spotted fever, and it is feared because of its bite. In rare instances, attachment of the dog tick over the spinal cord or at the base of the skull results in an illness called tick paralysis.

37. A newly created problem in New Jersey is that caused by the lone-star tick, Amblyomma americanum. The greatest concentration of these ticks is in the Cumberland-Atlantic-Cape May County area, where deer are plentiful. It is probable that this species was introduced into the area on imported deer and found the environment favorable. Thousands of specimens of this species have been observed during the last 3 or 4 years. It appears that the problem is expanding. The lone-star tick is a recognized vector of Rocky Mountain spotted fever in certain parts of the United States.

38. Black flies (Simuliidae) are produced principally in fast-flowing streams and constitute very localized problems in recreational areas and communities located in the mountains. These insects are most common in late May and early June.

39. Stable flies (Stomoxys calcitrans) are somewhat of a summer nuisance along beaches of the Delaware Bay. Breeding may occur in trash along margins of the Bay shore.

40. Chiggers (Eutrombicula alfreddugesi) are uncommon in the Delaware basin. These mites, or "red bugs," are known to occur in Sussex County, Delaware, and in Atlantic County, New Jersey.

PRESENT STATUS OF VECTOR CONTROL PROGRAMS

Legal Basis for Vector Control

41. The 4 States of the Delaware basin have statutory provisions that aim to correct, as nuisances, environmental health hazards associated with various insanitary conditions. When not specifically expressed, correction of public health problems associated with mosquitoes, flies, and other insects is usually implied. This is usually codified under various State laws, rules, and regulations. The owner on whose property a health hazard occurs is generally held to be responsible for taking necessary corrective action under these laws.

42. Enabling legislation providing specifically for mosquito abatement exists in the 4 States.

43. Federal properties. The provision of preventive measures or operation of vector control activities on Federal properties is a responsibility usually accepted by the sponsoring Federal development or operating agency.

State Programs

New Jersey

44. Mosquito abatement legislation. New Jersey was the first State in the United States to enact mosquito *control legislation*. A law passed in 1906 made it the responsibility of the State Agricultural Experiment Station to investigate and make recommendations regarding the mosquito problem. In 1912 this law was amended to provide for the establishment of county mosquito extermination commissions. The 1912 legislation is still the basic law.

45. Mosquito extermination commissions. At present, 16 active county mosquito extermination commissions represent the core of mosquito control activities in the State. The 5 counties without commissions are all located along Delaware River and Bay (fig. 2).

46. Mosquito control operations. Methods of mosquito control now being generally used by the various commissions include: (a) permanent water management in all of its phases (tidal-marsh ditching, dredging, etc.), (b) destruction of larvae, and (c) fogging, misting, and spraying for adult control. The use of chemicals has been very minor in relationship to the total program.

47. Technical guidance and coordination. The Director of the State Agricultural Experiment Station is charged by law with the responsibility of approval of plans and estimates of the county

commissions as well as coordinating the county programs. To provide for greater central control and coordination, there was created by the Legislature in 1956 a permanent State Mosquito Control Commission.

48. Technical assistance by entomologists of the State Agricultural Experiment Station has been given to the county mosquito extermination commissions and to municipalities and groups of individuals in counties without commissions.

49. Surveillance and research activities. The standard mosquito light trap, which was developed by the Department of Entomology of the New Jersey Agricultural Experiment Station, has been operated throughout the State since 1932. This has been one means of maintaining continuous surveillance on potential disease vectors in the State. Recent research projects of the State Experiment Station have included investigations on the newer insecticides, biology and ecology of several species of mosquitoes--especially *Mansonia perturbans* and *Culiseta melanura*--and vector-encephalitis relationship studies in birds. The Experiment Station has cooperated with the State Division of Fish and Game in studying the effects of impoundments and water level management practices on mosquito breeding in salt-marsh areas.

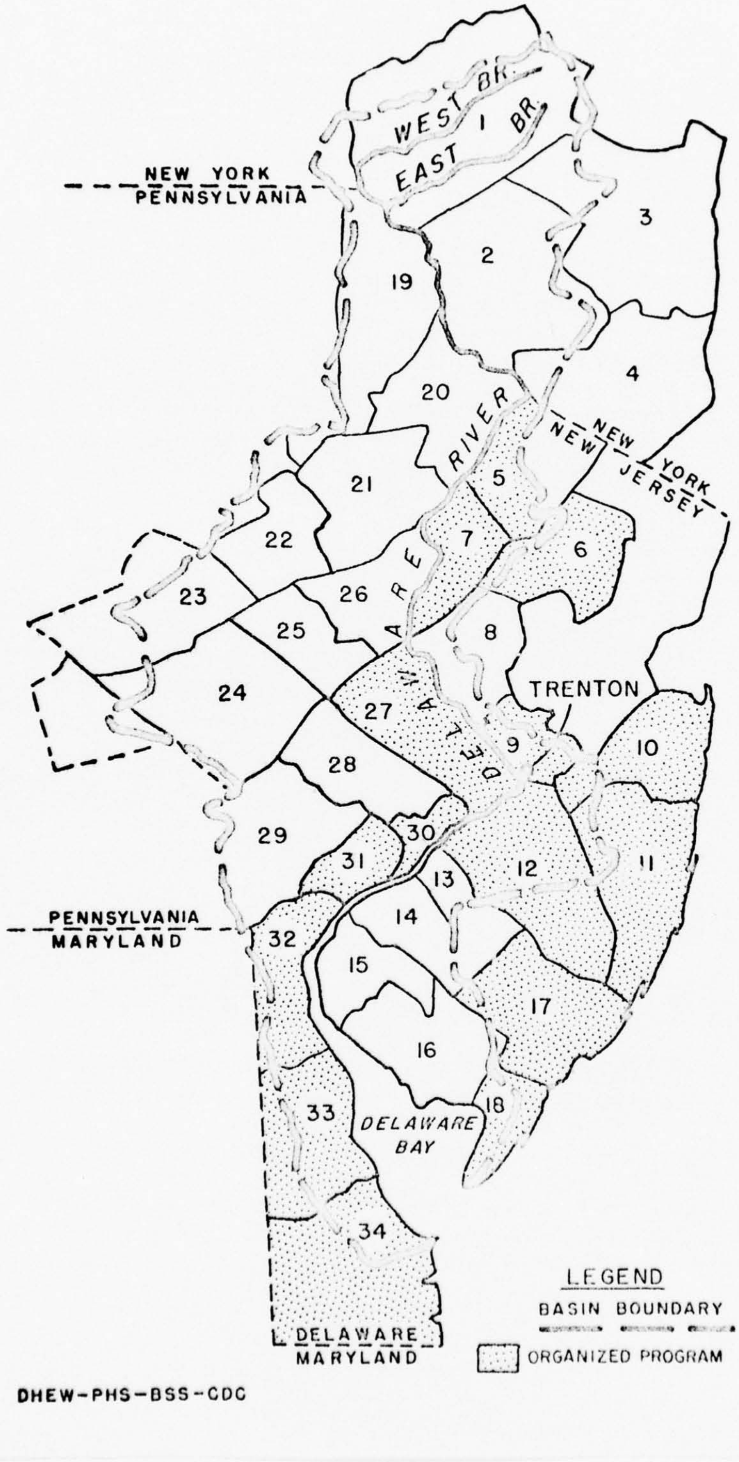
50. State aid. Beginning in 1949, yearly State appropriations have supported an airplane spraying program in seashore counties for reducing "peak" broods of adult salt-marsh mosquitoes. After 2 years of such control in 4 counties, the program was expanded to include the 5 counties of Monmouth, Ocean, Burlington, Atlantic, and Cape May. The annual appropriations for this work have ranged from $50,000 to $60,000. In 1956, a total of $75,000 was appropriated to the Experiment Station for aid to counties for the construction and reconstruction of ditches, dikes, pumps, gates, and fills in connection with mosquito control.

51. Education. Published proceedings of annual meetings of the New Jersey Mosquito Extermination Association, which was founded in 1913, have contributed a wealth of information pertaining to mosquito control. In 1945, Dr. T. J. Headlee published a book on "The Mosquitoes of New Jersey and Their Control."

New York

52. Vector control legislation. In 1916, New York first passed laws providing specifically for the establishment of mosquito extermination commissions in Suffolk and Nassau Counties. The present law restricts the formation of mosquito control commissions to Suffolk County. However, an amendment to the State public health law passed in 1948 authorizes the board of health of a town or village to take all necessary steps for the control of mosquitoes, black flies, punkies, ticks, and other insects detrimental to health within their jurisdiction.

Fig. 2. ORGANIZED MOSQUITO CONTROL IN COUNTIES IN THE DELAWARE RIVER BASIN



COUNTIES

NEW YORK
1. DELAWARE
2. SULLIVAN
3. GREENE
4. ORANGE

NEW JERSEY
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9. MERCER
10. MONMOUTH
11. OCEAN
12. BURLINGTON
13. CAMDEN
14. GLOUCESTER
15. SALEM
16. CUMBERLAND
17. ATLANTIC
18. CAPE MAY

PENNSYLVANIA
19. WAYNE
20. PIKE
21. MONROE
22. CARBON
23. SCHUYLKILL
24. BERKS
25. LEHIGH
26. NORTHAMPTON
27. BUCKS
28. MONTGOMERY
29. CHESTER
30. PHILADELPHIA
31. DELAWARE

DELAWARE
32. NEW CASTLE
33. KENT
34. SUSSEX

DHEW-PHS-BSS-CDC

ATLANTA, GA. JULY, 1957

59-5-6

53. Vector control operations. Such operations in upstate New York in the Delaware basin are sporadic and limited principally to fogging operations in the vicinity of summer hotels. Some of the hotels have contracts with local pest control operators for such work.

54. Technical assistance is provided by the State entomologist's office.

55. Research projects carried on by the New York State Science Service have included studies on the control of black flies, nuisance gnats, greenhead flies, and ticks.

Delaware

56. Mosquito control legislation. Delaware's legislation dates back to 1933, when a State Mosquito Control Commission was created. In 1939, the Legislature transferred the responsibility for mosquito control to the State Highway Department, which currently has the delegated authority for the control of mosquitoes in Delaware.

57. Mosquito control operations. The Mosquito Control Division of the State Highway Department carries on 2 principal activities--maintenance of an extensive system of drainage ditches, particularly in Sussex County, and contract aerial spraying of tidal marshlands.

58. Technical guidance and coordination. Under a continuing formal agreement of long standing, the State Highway Department receives technical supervision from the Department of Entomology of the University of Delaware. At the invitation of the Chief Engineer of the State Highway Department, there was recently created a State Mosquito Control Advisory Committee. This coordinating committee is comprised of officials from the State Highway Department, the U. S. Air Force, the State Health Department, the State Game and Fish Commission, and the University of Delaware.

59. Surveillance and research activities. The Department of Entomology has maintained light trap records in the State for 25 years. Basic research has been conducted on mosquito biology, toxicity of insecticides, effectiveness of new insecticides, and the effects of mosquito control on muskrat populations. Recently, a 3-year cooperative study with the U. S. Fish and Wildlife Service was completed on mosquito production in impounded and unimpounded marshlands on the Bombay Hook National Wildlife Refuge, in Kent County.

60. Appropriations for mosquito control. Prior to 1956, the annual State appropriation was about $125,000. Because of excessive numbers of salt-marsh mosquitoes in Kent County in 1956, the Legislature made an emergency supplementary appropriation of $225,000 for calendar year 1956. In June 1957, the State Legislature appropriated $471,000 for each of the next 2 fiscal years (effective July 1, 1957).

61. Education. The Department of Entomology of the University of Delaware has prepared many publications pertaining to mosquitoes and their control. Publications on other insects of medical importance have included horse flies and ticks.

Pennsylvania

62. Mosquito control legislation. Pennsylvania's mosquito abatement law was originally passed in 1935. This law provided for the establishment of county extermination commissions in any county of the State, except a county of the first class (1,800,000 population or over).

63. Mosquito extermination commissions. Three counties in Pennsylvania--Blair, Delaware, and Bucks--have established mosquito extermination commissions under the State law. In addition, organized mosquito control is conducted in Philadelphia.

64. Mosquito control operations. Permanent control measures have included filling and drainage. Hydraulic fill operations by the Corps of Engineers have eliminated extensive mosquito breeding areas of the great marshes below Philadelphia. Plane spraying of marshes, ground spraying, and fogging operations have been utilized for the temporary control of mosquitoes in Bucks and Delaware Counties, and in other areas of southeastern Pennsylvania.

65. Technical guidance. Because of direct and indirect health problems involved, the Pennsylvania Department of Health has taken the lead in mosquito control, through assisting other State departments, corporations, municipalities, and individuals.

66. Surveillance. The Pennsylvania Department of Health has operated mosquito light traps throughout the State.

Cooperative Federal-State Programs

67. Epidemic intelligence. In recent years a valuable type of epidemic intelligence and assistance on communicable disease problems has been rendered States on a national scale by the location of Federal public health specialists at strategic points for collecting information, reporting thereon, and providing prompt assistance on the epidemiologic aspects related to these problems. Under this arrangement, Public Health Service veterinarians assigned to New Jersey and Delaware rendered valuable assistance in connection with the outbreaks of mosquito-borne encephalitis in these States during 1956. These specialized activities have been carried out in addition to the general disease survey services provided by State departments of health.

68. Research projects. During the 3-year period, 1953-55, studies were conducted to determine the effects of impoundments and water level management practices on mosquito breeding in salt-marsh areas in New Jersey (Cape May and Atlantic Counties) and Delaware (Bombay Hook National Wildlife Refuge in Kent County). This cooperative work was undertaken by the State Divisions of Fish and Game, the Agricultural Experiment Stations, the U. S. Fish and Wildlife Service, and the U. S. Department of Agriculture.

69. Cooperative investigations by several agencies on the epidemiology and control of encephalitis (EEE) in captive pheasants have been carried out in New Jersey during the past few years. Participating agencies have included the New Jersey State Department of Health, the State Fish and Game Commission, the State Agricultural Experiment Station, the U. S. Army Epidemiological Board, the University of Pittsburgh, and the Public Health Service.

70. Technical training courses for vector control personnel have been given in the 4-State area. When requested, training aids and instructors are furnished by the Public Health Service. Such courses are sponsored by State and local health departments in accordance with their specific needs. An example of such activity was a training course on mosquito control, presented to employees of the New York City Health Department in May 1957.

71. A "New Jersey Short Course" has been given on 2 occasions to field and administrative personnel of county mosquito extermination commissions. This training course has been conducted by the State Agricultural Experiment Station staff with the assistance of more than a dozen experienced lecturers from outside the station's research and service field.

72. Epidemic aid to States may be made available during times of emergency. This type of aid was provided the States of New Jersey and Delaware in connection with outbreaks of encephalitis among horses in 1956. Based upon a formal request to the Public Health Service, a veterinarian was assigned to New Jersey and an entomologist to Delaware.

73. Project evaluation services and technical consultation on vector control are provided to the Corps of Engineers, Forest Service, Soil Conservation Service, and National Park Service by the Public Health Service in cooperation with State health departments. These activities are in accordance with existing agreements or memorandums of understanding and in fulfillment of established responsibilities.

74. Technical consultation is also provided to the national office of the Boy Scouts of America in connection with their Jamborees. In preparation for the 1957 Jamboree, assistance was given by the

Public Health Service and the Pennsylvania Department of Health in the control of ticks, mosquitoes, and other vectors at the Valley Forge Memorial Park in Montgomery County, Pennsylvania.

EFFECTS OF WATER AND RELATED LAND RESOURCE DEVELOPMENTS ON VECTOR PROBLEMS

75. Specific information on the types of projects to be constructed in the Delaware basin is not presently available. However, it is assumed that there will be several of each of the following types of projects: storage reservoir, small floodwater detention reservoir, flood control reservoir, water supply reservoir, wildlife impoundment, farm pond, drainage, and stream-channel improvement.

76. Based on conditions at existing water resource developments in the Delaware River watershed, it is envisioned that many features of the proposed projects will actually benefit vector control. Development of the flood control and watershed protection projects should be beneficial from a mosquito control standpoint since better water management would be effected. Floodwater mosquito problems in downstream areas would be alleviated. Development of drainage and channel improvement projects would tend to reduce the extent of existing mosquito sources. Low-lying mosquito breeding areas in the vicinity of dredging projects could be permanently eliminated by the use of hydraulic fills.

77. The following conditions resulting from the design, construction, operation, or maintenance of the projects would favor mosquito production:

(a) Shallow vegetated areas in reservoirs.
(b) Seepage areas below dams and dikes.
(c) Ponded water in borrow pits and other undrained areas.
(d) Excessive emergent vegetation or debris in drainage ditches.
(e) Inadequate control of water in wildlife impoundments.

78. Farm ponds, especially those stocked with fish, have a low mosquito potential. In the construction of a pond it is desirable to clear the site of trees and brush, to provide for relatively steep side slopes, and to provide for a water control structure.

79. Water supply reservoirs. Existing water supply reservoirs in the upper Delaware basin area of New York and Pennsylvania have not created mosquito problems. In general, the shorelines are steep and clean.

80. Flood control reservoirs. The greatest potential for mosquito production in this type of project is the shallow water of lateral embayments and the quiet backwater areas. The quiet, shallow water is conducive to the growth of cattail and other emergent plants, which in turn favors breeding of aquatic-plant mosquitoes (*Mansonia*

perturbans). It is important in the design of the project to make adequate provision for a draw down of water levels. This not only controls M. perturbans, but it expedites shoreline maintenance operations. Other preventive measures recommended for flood control reservoirs include preimpoundage clearing and drainage of marginal areas.

81. Wildlife impoundments. This relatively new method of controlling salt-marsh mosquitoes--and concurrently providing food and shelter for wildlife--by diking and flooding of salt marshes appears to have considerable merit. When the water is properly controlled, the production of temporary-water mosquitoes (Aedes) is virtually eliminated. It should be pointed out, however, that this method may favor the production of such permanent-water species as Anopheles quadrimaculatus and Culex salinarius. Proponents of this method emphasize that the benefits received far exceed the adverse effects because the latter two species are night biters only and disperse relatively short distances.

VECTOR CONTROL PLAN

Introductory Statement

82. Future water resource developments and related land use projects in the Delaware River basin may create new and aggravate existing vector problems unless proper preventive and control measures are provided. These measures should be planned and built into each project from its inception and continued as a part of regular operations. Vector control should be coordinated with other basic interests, such as agriculture, soil and water conservation, flood control, land reclamation including dredging and filling, wildlife management, and recreation. When this is done, the maximum benefits can be derived from developments in the basin with minimum deleterious effects upon the health and welfare of the resident and tourist population.

83. In the planning of water and land resource developments, the basic agency responsibilities in vector control programs should be recognized and agreed upon. The cardinal principle upon which these programs should be developed is that: "The full responsibility for vector prevention and control should be assumed by the individual or agency creating the problem." This would mean the construction and/or operating agency for State or Federal projects, and the owner of private projects.

84. In general, the delegation of basic responsibilities for vector control on projects developed in other areas has been as outlined in the following tabulation. These delegations include responsibility for financing as well as carrying out the activity indicated.

Delegation of Responsibility for Vector Control on Water Resource Development Projects

	Project Sponsor		
Activity	Federal	State	Private
Vector Control Operations	COA	COA	Owner
Surveillance	PHS*	SD**	SD**
Special Research	PHS*	SD**	SD**
Technical Assistance	PHS*	SD**	SD**

COA - Construction and/or Operating Agency.
PHS - U. S. Public Health Service.
SD - State Health Department, State Agricultural Experiment Station, and other State agencies responsible for vector control.
* - In close cooperation with State agencies.
** - With the assistance of the Public Health Service as requested.

85. There follows a brief discussion of overall requirements for the vector prevention and control plan for the Delaware basin. The plan provides 4 basic types of activity: (a) Vector control operations, (b) surveillance, (c) special research, and (d) technical assistance.

Vector Control Operations

86. For the control of existing vector problems, the present system of organized mosquito control agencies should be continued as the core of mosquito control activities. The promotion of organized mosquito control in all counties along the Delaware Bay would be a benefit to the entire State of New Jersey.

87. On future water resource development projects, the agency or individual who creates the problem should carry out control measures based on plans developed by the appropriate technical agency. The operating agencies should receive from these technical agencies guidance and up-to-date information on the most effective and economical means for the prevention and control of mosquitoes and other vectors associated with water utilization projects.

Surveillance

88. Continuing analysis of State disease vector problems is a specific concern as well as the prerogative of State departments of health. Also, the Public Health Service has authority to and does participate in such appraisals. A program of continuing surveillance of disease vector problems to guide the efforts of other activities is a basic element of this plan.

89. In view of the large populations of *Culex pipiens* in the basin, coupled with the demonstrated ability of New Jersey strains of this species to transmit St. Louis encephalitis in the laboratory, continuing surveillance should be made to lessen any potential threat of an epidemic of this disease.

Special Research

90. Research activities are essential in order to develop sound programs of vector control. At present there is great need for an expansion of the cooperative type of investigations by State and Federal agencies representing the various basic interests such as wildlife conservation, health, agriculture, etc.

91. The following are some of the vector research problems in the Delaware basin that currently require attention:

(a) The natural history and the control of eastern equine encephalitis.

(b) The bionomics and control of salt-marsh mosquitoes.

(c) The bionomics and control of the following fresh-water mosquitoes: Culex pipiens, Aedes vexans, Mansonia perturbans.

(d) The bionomics and control of greenhead flies, deer flies, and biting gnats.

(e) Improved equipment and machines for water management and insecticidal and herbicidal application.

(f) Improved methods for the control of ticks in recreational areas adjoining water development projects by the use of herbicides.

(g) Improved multipurpose techniques for use in the design, operation, and maintenance of water impoundments so as to minimize vector production.

Technical Assistance

92. The technical agencies should provide constructing and operating agencies with appropriate assistance in planning and executing vector control operations. Careful surveys should be made of individual projects or programs to determine specifically: (a) whether project development will result in an increase or decrease in insect abundance in the area; (b) the particular characteristics of local or project conditions that will constitute a health problem or benefit; and (c) what measures for vector control will best fit local and project conditions and basic project functions.

93. Other types of technical assistance should include development of acceptable procedures for routine appraisal of control operations, providing of technical assistance in training personnel, conducting investigations on special problems which may arise, and the overall technical evaluation of vector control programs.

94. The technical agencies should prepare and disseminate appropriate educational materials pertaining to the prevention and control of vector problems to the agencies responsible for the construction and operation of water utilization projects.

SUMMARY AND CONCLUSIONS

95. The nature and importance of public health insect problems vary considerably between the northern mountainous and hilly areas and the southern coastal and tidewater areas of the Delaware basin. In general, insect problems of the upper basin are localized and minor, while those of the lower basin are extensive and of major importance.

96. The most important public health insects in the Delaware basin are mosquitoes--both salt-marsh and fresh-water types.

97. Of the principal insect-borne diseases known to occur in the area (malaria, Rocky Mountain spotted fever, and encephalitis), encephalitis has the highest potential. Although this disease has rarely affected humans in the basin, it has caused serious losses among horses and captive pheasants. Mosquito-borne encephalitis has a high potential because there is presently no known therapeutic treatment and human immunization is not available.

98. The bog mosquito, *Culiseta melanura*, has been implicated as the primary vector for maintaining the basic chain of eastern equine encephalitis (EEE) in nature (bird-mosquito-bird). It is not known, however, whether *C. melanura* is responsible for human and horse outbreaks of EEE, or whether some other mosquitoes, such as *Aedes*, *Psorophora*, or *Mansonia* are the vectors.

99. The most formidable biting insects in Delaware and southern New Jersey are the salt-marsh mosquitoes, particularly *Aedes sollicitans*. This migratory species is especially troublesome in Kent and Sussex Counties, Delaware, and in Salem, Cumberland, and Cape May Counties, New Jersey.

100. For the basin as a whole, problems caused by fresh-water mosquitoes actually exceed those caused by salt-marsh mosquitoes. This is due to the ubiquity of the domestic urban mosquito, *Culex pipiens*, and the floodwater mosquito, *Aedes vexans*. Domestic mosquito problems have become greatly intensified in recent years because of rapid industrial and urban expansion in the lower Delaware basin, with the accompanying drainage and pollution problems.

101. The fresh-water aquatic-plant mosquito, *Mansonia perturbans*, presents a singular problem because of its intimate association with cattail and other emergent vegetation, and the fact that its larvae are attached to the roots and submerged stems of plants.

102. In localized areas, particularly along the Delaware Bay shore, considerable annoyance may be caused by greenhead flies, deer flies, biting gnats, and ticks. Black flies are only occasionally a

problem in mountainous areas of the upper watershed area. Minor problems in the basin are caused by stable flies and chiggers.

103. All 4 States of the Delaware basin have enabling legislation providing specifically for mosquito abatement. Under these laws, organized mosquito control programs in the basin area are now operating in several counties in New Jersey, in Delaware and Bucks Counties, Pennsylvania, and in the entire State of Delaware.

104. Organized mosquito control programs have performed a very beneficial service for the area. These programs have included vector control operations directed at both salt-marsh and fresh-water mosquitoes. Technical guidance and coordination have been given by the New Jersey Agricultural Experiment Station, the University of Delaware, and the Pennsylvania Department of Health. Research projects, technical assistance, surveillance, and education have been important activities of these programs.

105. Cooperative Federal-State programs in the 4-State area have included epidemic intelligence services, research activities on mosquito production in salt-marsh impoundments and on encephalitis in captive pheasants, technical training courses for vector control personnel, epidemic aid to States during outbreaks of encephalitis, project evaluation services provided to Federal agencies, and technical consultation to the national office of the Boy Scouts of America.

106. Based on conditions at existing water resource developments in the area, it is envisioned that many features of the contemplated projects of the Delaware basin will actually benefit the control of mosquitoes and allied problems. This includes flood control projects, and drainage and channel improvement works.

107. The following conditions resulting from the design, operation, or maintenance of the projects would favor mosquito production: (a) shallow vegetated areas in reservoirs, (b) seepage areas below dams and dikes, (c) ponded water in borrow pits and other undrained areas, (d) excessive emergent vegetation or debris in drainage ditches, and (e) inadequate control of water in wildlife impoundments.

108. The greatest potential for mosquito control in flood control reservoirs is the shallow water of lateral embayments and the quiet backwater areas. The quiet, shallow water is conducive to the growth of cattail, which in turn favors breeding of aquatic-plant mosquitoes (Mansonia perturbans). It is important in the design of the project to make adequate provision for a draw down of water levels.

109. In planning vector control programs for future water resource developments and related land use projects in the Delaware basin, the cardinal principle upon which these programs should be

developed is that: "The full responsibility for vector control should be assumed by the individual or agency creating the problem."

110. In order to safeguard the public health through the control of insect problems, a 4-phase vector control plan is presented, including vector control operations, surveillance, special research, and technical assistance.

111. In executing the plan, it is essential: (a) that adequate funds be provided the constructing and operating agencies for the vector control operations; (b) that continuing analysis be made of public health insect problems in order to guide the development agencies; (c) that research activities be expanded on the bionomics and control of insect vectors associated with water projects; and (d) that technical assistance be provided the water development agencies in planning and executing vector control operations--including site surveys--in formulating control programs that are compatible with multipurpose functions, and in appraising control operations.

112. It is concluded that prosecution of the vector control plan will control the potential problem, will benefit the public health, and will promote maximum benefits from the development of the Delaware River basin.

REPORT ON THE

COMPREHENSIVE SURVEY

OF THE

WATER RESOURCES

OF THE

DELAWARE RIVER BASIN

APPENDIX M

HYDROLOGY

PREPARED BY THE
U. S. ARMY ENGINEER DISTRICT, PHILADELPHIA
CORPS OF ENGINEERS
PHILADELPHIA, PA.
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APPENDIX M

HYDROLOGY

SECTION I - GENERAL

1. SCOPE. There are presented in this appendix hydrologic data, and their sources, for the Delaware River basin, and the analyses of these data with regard to the formulation of a comprehensive plan for development of the water resources of the basin. Included are analyses of all levels of surface runoff from high flows to low flows, probable flow frequencies of both instantaneous peaks and low flow volumes, development and application of unit hydrographs in the derivation of hypothetical floods for design purposes, routing of all flows both natural and modified, and a study of water availability in the basin for relating reservoir storages to yields. The analyses of ground water and water quality were performed by other Federal agencies and are presented in other appendixes to this report. Although about 70 reservoir sites in all parts of the basin were investigated, the specific reservoirs covered in this appendix are limited to those which are proposed as units of the recommended comprehensive plan of water resources for the Delaware River basin.

2. GEOGRAPHY. The Delaware River basin is an elongated area lying generally between latitudes 39° 00' N. to 42° 30' N. and longitudes 74° 30' W. to 76° 00' W., approximately 75 miles inland from the Atlantic coast. The basin averages about 55 miles in width and 240 miles in length with the long axis oriented in a north-south direction. Elevations range from about 10 feet above mean sea level at Trenton, New Jersey, to 2,600 feet near the headwaters and the equivalent main stream slope is about 5.0 feet per mile. The basin is bisected by the Blue-Kittatinny Mountain Range which runs northeasterly-southwesterly crossing Delaware River at Delaware Water Gap and near the midpoint of the north-south axis of the basin. The area in the northern half of the basin consists of the eastern slopes of the Poconos, western slopes of the Catskills and adjacent mountains. The lower half of the basin beginning south of the Blue-Kittatinny Range is characterized by rolling hills of moderate height which gradually flatten out southward to the low area in the Atlantic Coastal Plain. The upper half of the basin, due to its mountainous topography, is conducive to the occurrence of storm centers of long duration - large area rainfall with the normal orientation of the isohyetal patterns parallel to the general direction of the ground elevation contours. Coastal tropical storms occur over the lower portion of the basin and may produce extremely heavy rains near the coast with little or no orographic influence. Generally this non-orographic pattern will not be centered inland further than the Blue-Kittatinny Mountain Range. The drainage area of the entire basin above the mouth of Delaware Bay

(a line connecting Cape May and Cape Henlopen) is 12,765 square miles. This drainage area includes all streams tributary to the bay comprising 1,440 square miles, but excludes the water surface of the bay which is approximately 780 square miles.

3. CLIMATOLOGY. The climatology of the Delaware River basin is of interest in the present study with particular regard to its effect on floods, droughts and general availability of water. Although very near the Atlantic coast, its climate is largely continental. The air masses that influence the climate move predominantly from the interior of North America, being modified by influences of the Great Lakes and the Appalachian Mountains to the west. Generally west to southwest airflow with extended overland travel brings the hot dry weather which is responsible for occasional summer droughts. North to south airflow occurs in winter, originating in the cold highs over Canada and bringing arctic air into the basin. The average annual temperature is about 51°F., and temperatures below zero or above 100°F. are rare. Precipitation is moderate, about 44 inches per year, and is well distributed throughout the year. Summer totals of precipitation are slightly higher than in winter. Showers and thunderstorms produce most of the precipitation during the warm months. During the cool months coastal storms account for most of the precipitation. The heaviest and most extended rains in this region are experienced with storms of tropical origin occurring during late summer and autumn. Winds of damaging force accompany hurricanes, northeasters and occasionally the severe thunderstorms of the summer. The following paragraphs discuss the elements of climate mentioned above with supporting data to show averages, means and extremes of temperature for key stations in the basin. Maps of average annual temperature and evaporation are included. Storm types are discussed with respect to their origin, movement and general severity. Noteworthy periods of drought are also indicated.

4. TEMPERATURE. The temperature regimen of the Delaware basin is moderate. Flood threats from ice jams and snow melt runoff are rare. The average annual temperature ranges from about 45°F. in the northern part of the basin to about 55°F. in the southern part, and for the most part temperatures throughout the basin vary between 28°F. and 75°F. Temperatures below zero are, of course, more frequent in the northern part of the basin while those above 100°F. occur more often in the southern part, but such extremes of temperature are infrequent. A summary of extremes and normals of monthly maximum, minimum, and mean temperatures for Port Jervis, Trenton, Philadelphia, and Wilmington are shown in table M-1 and on plate 1. Isotherms of average annual temperature are shown on plate 2. Temperature recording stations in and near the basin are shown on plate 3.

TABLE M-1

MONTHLY NORMALS OF MAXIMUM, MINIMUM, AND MEAN TEMPERATURES FOR PERIOD 1921-50

Station		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Extreme Day
Port Jervis	Max.	34.4	35.3	46.3	60.2	71.9	79.9	84.0	81.4	75.4	63.4	48.9	37.2	103
	Min.	16.7	16.4	25.3	35.7	46.2	54.8	59.7	57.8	51.5	40.0	30.3	20.8	-26
	Mean	27.7	28.3	36.9	48.5	59.7	68.1	73.1	70.8	63.6	53.2	41.4	30.0	
Trenton	Max.	39.8	40.3	50.0	60.3	72.0	80.6	84.6	82.2	76.1	65.4	53.5	42.0	106
	Min.	25.4	25.0	32.5	41.0	51.6	60.9	66.0	64.2	57.9	46.8	37.7	27.9	-14
	Mean	32.6	32.7	41.3	50.7	61.8	70.8	75.3	73.2	67.0	56.1	45.6	35.0	
Philadelphia	Max.	41.5	42.2	51.7	61.6	72.8	81.3	85.3	83.0	77.2	66.6	54.7	43.7	106
	Min.	28.2	28.0	35.2	43.8	54.5	63.8	69.0	67.3	61.3	50.4	40.8	31.0	-11
	Mean	34.9	35.1	43.5	52.7	63.7	72.6	77.2	75.2	69.3	58.5	47.8	37.4	
Wilmington	Max.	41.8	42.8	53.0	63.2	74.6	83.1	86.7	84.6	78.8	67.2	55.3	43.9	107
	Min.	24.7	24.6	32.0	40.4	51.0	60.4	65.0	62.9	57.1	45.2	35.7	26.2	-15
	Mean	33.3	33.7	42.5	51.8	62.8	71.8	75.9	73.8	68.0	56.2	45.5	35.1	

Source: U. S. Weather Bureau - Port Jervis - Climatic Summary of United States
Trenton - Local Climatalogical Data
Philadelphia - Local Climatalogical Data
Wilmington - Local Climatalogical Data

5. STORMS. Storm occurrences in the Delaware basin are of two general types, namely, storms of tropical origin (hurricanes) and storms of extra-tropical origin such as thunderstorms and northeasters. These storms occur separately and together, with the most intense precipitation resulting from a combination of both types. Movement of warm moist air into contact with surrounding air of lower temperature, produces the violent thunderstorms and intense precipitation of the summer months in this area, and the northeasters of the cool months. The latter are of coastal origin and are accompanied by severe winds and flood-producing precipitation. Some of the worst floods of record, however, have been associated with hurricanes. Although the nature of hurricane genesis and movement are generally understood, prediction of hurricane occurrences is uncertain due to the variable nature of the circulation patterns which control them. There is no specific locality at which hurricanes may cross the coast. From their point of tropical origin they may move directly west, crossing into Mexico, Texas or the Gulf states. They may cross the Atlantic coast anywhere from Florida to Maine, or they may remain entirely at sea depending largely on the point of origin and the associated circulations. The paths of hurricanes that have crossed or passed in the vicinity of the Delaware basin are shown on plate 4. Descriptions of individual thunderstorms, northeasters, and hurricanes with respect to precipitation amounts and location in the basin are presented in section II. Records show that most severe storms occur in the Delaware basin when a hurricane joins an extra-tropical storm and the two storms travel together exhibiting a characteristic isohyetal storm pattern having two major storm centers. Hurricane "Diane," in August 1955, was of this type.

6. DROUGHTS. The Delaware River basin lies within the general climatic province classed as humid. Drought conditions may be said to prevail in a humid region when vegetation growing under natural conditions becomes desiccated or defoliates unseasonably and crops fail to mature due to lack of rainfall, or when precipitation is insufficient to meet the needs of established human activities. Meteorologists agree that it would be difficult, if not impossible, to arrive at a more specific definition largely because the degree of injury which a prolonged dry spell can do to plant life depends on several things besides the accumulated deficit of rainfall. It depends, too, on the prevailing temperatures, amount of wind movement, character and condition of the soil, rate of evaporation, degree of cloudiness, and the stage reached in the plant growth cycle. What would constitute a drought agronomically in one part of a state would not necessarily be so designated in another part. J. C. Hoyt 1/ 2/ in his drought

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1/ Hoyt, J. C., Drought of 1930-34: U. S. Geological Survey Water-Supply Paper 680, 106 pp., 1936.
2/ Hoyt, J. C., Drought of 1936, with discussion of the significance of drought in relation to climate: U. S. Geological Survey Water-Supply Paper 820, 62 pp., 1938.

studies concluded that in humid and semi-arid states serious drought effects do not result unless the annual precipitation is as low as 85 percent of the mean; that is, an annual deficiency of 15 percent or more. Noteworthy droughts in Pennsylvania, listed by the Department of Forests and Waters, occurred in 1876, 1881, 1887, 1895, 1900, 1904, 1908, 1909, 1914, 1922, and 1930-31. A study of climatological data since 1931 shows additional droughts occurred in 1941 and 1957. The worst drought experienced throughout the Delaware River basin was in 1930 and the next most severe in 1895. A general drought over the entire United States occurred during the period 1930-34. During each of the five years of this drought period, except 1932, one or more of the 48 states in continental United States except Maine, Vermont, Louisiana, Mississippi and Arkansas, experienced a major drought. The average precipitation for each of the states in which portions of the Delaware River basin are located, together with the minimums prior to 1930 and during the 1930-34 drought are given in table M-2.

TABLE M-2
AVERAGE PRECIPITATION DATA FOR PERIOD 1881-1934

State	50-Year Mean 1881-1930 (Inches)	Minimum, 1930-34 Year	Minimum, 1930-34 Inches	Minimum, 1930-34 % of Mean	Minimum prior to 1930 Year	Minimum prior to 1930 Inches	Minimum prior to 1930 % of Mean
New York	39.01	1930	32.18	82	1908	33.54	86
New Jersey	45.89	1930	35.28	77	1895	37.29	81
Pennsylvania	42.47	1930	28.82	68	1895	33.51	79
Maryland-Delaware	41.89	1930	23.78	57	1895	34.47	82

SECTION II - PRECIPITATION

7. PRECIPITATION DATA. The U. S. Weather Bureau is the principal agency engaged in the collection and compilation of climatological data, including data on precipitation. Hourly and daily as well as total monthly precipitation amounts are published by the Bureau in its climatological data bulletin. The climatological data bulletin and the Corps of Engineers publication "Storm Studies" were the principal sources of rainfall data used in studies for this report. A number of stations located outside of, but immediately adjacent to, the Delaware River basin were utilized also in studies pertaining to the report.

8. PRECIPITATION STATIONS AND PERIODS COVERED BY RECORD. The Delaware basin is covered by a network of precipitation stations operated by the U. S. Weather Bureau. There are 153 official stations presently in operation within the drainage area of the Delaware River. Of these, 38 stations are equipped with continuous recording rainfall gages. The remaining 115 stations are equipped with standard non-recording gages which are read one or more times daily. The locations and types of all stations currently operating in the area are shown on plate 3. Information on station location, elevation, exposure, instrumentation, and period of record for all existing and discontinued stations is summarized in the U. S. Weather Bureau publication titled "Substation History."

9. ANNUAL PRECIPITATION. Average annual precipitation within the watershed of the Delaware River is 44 inches per year. It varies from about 40 inches in certain sections of the lower portion of watershed and in the Delaware Bay area to approximately 60 inches along the ridges in some of the mountainous regions of the headwaters. A map showing isohyetal lines of average annual precipitation for the general Delaware River area is shown on plate 5. Table M-3 includes means and extremes of annual precipitation for 18 stations during the period 1931-52.

10. SEASONAL PRECIPITATION. Seasonal variation of rainfall for the Delaware River basin is indicated on plate 6 which shows the average precipitation during the growing season, May through September, in percent of the average annual. The May through September rainfall averages 47.9 percent of the average annual, or 21 inches, and the October through April average rainfall is 23 inches, or 52.1 percent of the average annual for the basin.

11. ANNUAL SNOWFALL. The average annual snowfall for stations located within the Delaware basin is published by the U. S. Weather Bureau in the "Climatic Summary." Based on a study of these data it was determined that the average annual snowfall varies from about 15 inches in the bay region to over 70 inches in the headwaters area and in the Pocono Mountains. The average annual snowfall at all stations

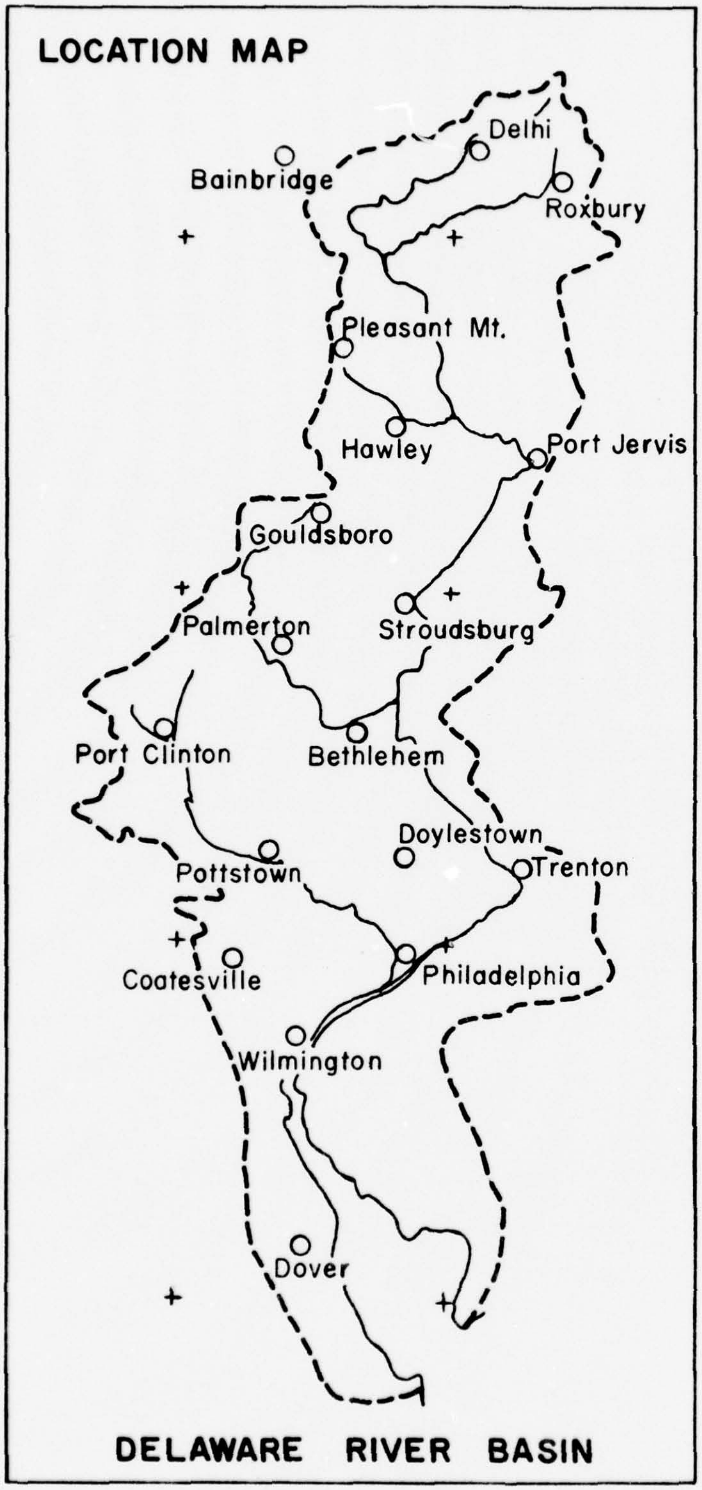

TABLE M-3

MINIMUM AND MEAN PRECIPITATION FOR PERIOD 1931-19

Station	Length of Record 1/ (Yrs.)		Jan.	Feb.	Mar.	Apr. Prec
		Max.	8.09	6.27	7.15	7.02
Dover	65	Mean	4.15	3.05	4.18	3.59
		Min.	1.98	1.08	1.74	.83
		Max.	7.10	6.02	6.63	6.30
Wilmington	59	Mean	3.82	2.80	4.07	3.66
(City Hall)		Min.	1.58	1.72	2.03	1.09
Philadelphia		Max.	7.04	5.68	6.73	6.70
(Shawmont)	56	Mean	3.53	2.67	4.05	3.54
		Min.	1.50	1.51	1.74	1.31
		Max.	6.88	6.08	7.06	7.03
Coatesville	64	Mean	3.55	2.74	4.06	3.74
(1SW)		Min.	1.32	1.62	1.59	1.35
		Max.	5.63	4.80	6.17	9.20
Pottstown	61	Mean	3.32	2.62	3.86	3.31
		Min.	.64	1.30	2.01	.86
		Max.	6.25	5.26	5.66	7.53
Doylestown	62	Mean	3.29	2.44	3.47	3.23
		Min.	1.16	1.06	1.39	1.25
		Max.	7.40	5.98	6.43	6.95
Trenton	64	Mean	3.86	2.89	4.16	3.63
		Min.	1.55	1.56	1.80	1.26
		Max.	6.22	5.54	6.36	8.20
Bethlehem	67	Mean	3.23	2.48	3.59	3.40
(Lehigh U.)		Min.	1.14	1.66	1.25	.85
		Max.	5.78	4.79	6.92	7.32
Port Clinton	62	Mean	3.45	2.56	4.20	4.01
		Min.	1.35	1.35	1.19	1.15
		Max.	6.60	4.40	7.50	7.83
Palmerton	35	Mean	3.13	2.24	3.60	3.21
		Min.	1.44	1.22	.93	.50
		Max.	6.71	5.20	8.91	10.78
Stroudsburg	35	Mean	3.57	2.68	4.11	3.86
		Min.	1.76	1.12	1.49	.86
		Max.	6.56	5.98	8.16	9.42
Gouldsboro	37	Mean	3.15	2.72	3.93	3.89
		Min.	1.47	.96	1.36	1.42
		Max.	5.17	4.85	7.93	9.10
Port Jervis	69	Mean	2.90	2.52	3.23	3.59
		Min.	1.00	1.44	1.19	1.02
		Max.	5.05	5.03	7.52	6.27
Hawley	50	Mean	2.84	2.57	3.52	3.41
		Min.	1.23	1.22	1.55	1.28
		Max.	6.55	4.55	9.76	6.71
Pleasant Mt.	31	Mean	3.45	2.79	4.01	3.93
		Min.	.84	1.43	1.53	1.60
		Max.	5.57	4.77	5.74	4.75
Bainbridge	42	Mean	2.77	2.38	3.29	3.13
		Min.	.73	1.18	1.73	2.07
		Max.	5.01	4.48	5.09	5.14
Delhi	28	Mean	2.76	2.39	2.97	3.20
		Min.	.95	1.05	1.58	1.77
		Max.	5.13	4.78	7.15	5.48
Roxbury	37	Mean	3.15	2.69	3.53	3.61
		Min.	1.04	1.20	1.65	1.45

1/ For reference only

TABLE M-3

MINIMUM AND MEAN PRECIPITATION FOR PERIOD 1931-1952; DELAWARE RIVER BASIN

Station	Length of Record 1/ (Yrs.)		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
						Precipitation in Inches									
		Max.	8.09	6.27	7.15	7.02	12.96	6.99	13.43	16.08	11.37	6.07	7.88	7.50	60.05
Dover	65	Mean	4.15	3.05	4.18	3.59	4.39	3.71	4.80	5.71	3.87	3.09	3.56	3.24	47.34
		Min.	1.98	1.08	1.74	.83	.62	1.18	1.68	.85	1.03	.95	.79	.91	32.21
		Max.	7.10	6.02	6.63	6.30	9.99	9.56	8.26	12.15	8.37	5.98	7.57	5.74	57.48
Wilmington	59	Mean	3.82	2.80	4.07	3.66	4.45	4.06	4.09	5.12	3.25	2.93	3.76	3.17	45.18
(City Hall)		Min.	1.58	1.72	2.03	1.09	.25	.46	1.46	1.39	.27	.35	.65	1.34	34.17
Philadelphia		Max.	7.04	5.68	6.73	6.70	8.51	7.68	9.47	10.32	7.56	7.30	8.03	5.92	61.62
(Shawmont)	56	Mean	3.53	2.67	4.05	3.54	4.21	3.65	4.99	4.53	3.26	2.95	3.77	3.34	44.49
		Min.	1.50	1.51	1.74	1.31	1.44	.69	1.38	1.28	.45	.57	.65	1.31	35.52
		Max.	6.88	6.08	7.06	7.03	9.14	12.18	7.80	13.29	6.96	7.62	7.42	7.10	56.36
Coatesville	64	Mean	3.55	2.74	4.06	3.74	4.48	4.62	4.52	4.90	3.32	3.08	3.76	3.42	45.92
(1SW)		Min.	1.32	1.62	1.59	1.35	1.11	.63	.74	1.25	.37	.82	.65	1.36	29.30
		Max.	5.63	4.80	6.17	9.20	10.67	5.78	7.79	5.45	8.06	7.99	6.98	5.17	57.16
Pottstown	61	Mean	3.32	2.62	3.86	3.31	4.25	3.79	4.67	3.27	3.33	2.63	3.64	3.01	41.70
		Min.	.64	1.30	2.01	.86	1.04	.55	.38	.43	.38	1.11	.61	1.37	33.03
		Max.	6.25	5.26	5.66	7.53	8.07	7.89	11.01	11.36	9.14	6.94	9.11	6.29	52.97
Doylestown	62	Mean	3.29	2.44	3.47	3.23	4.44	4.11	4.96	4.33	3.57	2.74	3.60	3.05	43.23
		Min.	1.16	1.06	1.39	1.25	1.20	.63	.18	1.21	.25	.66	.59	1.25	33.80
		Max.	7.40	5.98	6.43	6.95	8.86	9.10	11.80	11.44	11.92	5.95	8.46	7.32	61.70
Trenton	64	Mean	3.86	2.89	4.16	3.63	4.42	4.41	4.93	5.20	4.33	3.05	3.91	3.38	48.17
		Min.	1.55	1.56	1.80	1.26	1.38	.20	.46	2.14	.26	.52	.77	1.12	38.38
		Max.	6.22	5.54	6.36	8.20	9.68	9.98	11.97	10.27	10.80	6.13	7.05	5.90	54.95
Bethlehem	67	Mean	3.23	2.48	3.59	3.40	3.98	3.94	5.05	4.18	3.60	2.72	3.45	3.27	42.89
(Lehigh U.)		Min.	1.14	1.66	1.25	.85	.86	.25	1.17	1.65	.21	.76	.69	1.16	29.21
		Max.	5.78	4.79	6.92	7.32	11.18	6.12	10.59	13.20	9.88	7.85	7.40	6.88	64.04
Port Clinton	62	Mean	3.45	2.56	4.20	4.01	4.76	3.78	5.19	4.43	4.14	3.60	3.94	3.63	47.69
		Min.	1.35	1.35	1.19	1.15	1.13	.59	1.64	1.09	.11	1.26	.71	1.08	31.02
		Max.	6.60	4.40	7.50	7.83	9.03	7.62	11.62	9.99	10.22	6.97	7.84	5.71	61.73
Palmerton	35	Mean	3.13	2.24	3.60	3.21	4.04	4.30	5.27	4.49	3.88	3.10	3.65	3.22	44.13
		Min.	1.44	1.22	.93	.50	.77	1.52	.56	2.01	.43	.85	.28	.76	29.61
		Max.	6.71	5.20	8.91	10.78	7.76	9.00	11.55	9.90	10.07	9.05	8.72	7.95	64.04
Stroudsburg	35	Mean	3.57	2.68	4.11	3.86	4.11	4.58	5.06	4.38	4.31	3.25	4.45	3.84	48.20
		Min.	1.76	1.12	1.49	.86	1.13	.67	1.81	2.27	.12	1.03	.77	.95	39.58
		Max.	6.56	5.98	8.16	9.42	9.70	8.16	10.28	11.71	8.24	8.54	8.17	7.83	61.65
Gouldsboro	37	Mean	3.15	2.72	3.93	3.89	5.21	4.25	5.21	4.06	3.56	3.48	4.24	3.41	47.11
		Min.	1.47	.96	1.36	1.42	1.85	.97	1.05	.99	.14	1.65	.49	1.14	36.25
		Max.	5.17	4.85	7.93	9.10	8.76	8.62	11.35	10.13	8.43	9.60	7.45	6.93	56.90
Port Jervis	69	Mean	2.90	2.52	3.23	3.59	4.37	4.32	4.73	3.63	3.63	3.10	3.66	3.13	42.81
		Min.	1.00	1.44	1.19	1.02	1.48	1.55	.97	.79	.40	1.02	.71	.36	30.92
		Max.	5.05	5.03	7.52	6.27	8.15	6.08	12.94	11.45	8.36	7.10	6.16	5.95	58.08
Hawley	50	Mean	2.84	2.57	3.52	3.41	4.35	3.79	4.77	4.11	3.63	3.17	3.42	3.05	42.63
		Min.	1.23	1.22	1.55	1.28	2.06	1.46	.62	2.04	.11	1.32	.66	.93	30.48
		Max.	6.55	4.55	9.76	6.71	9.61	6.41	9.78	11.48	9.59	7.55	6.88	6.58	54.82
Pleasant Mt.	31	Mean	3.45	2.79	4.01	3.93	4.46	4.03	4.78	4.01	3.99	3.59	4.04	3.51	46.59
		Min.	.84	1.43	1.53	1.60	1.57	.59	.37	1.48	.62	.86	.45	1.00	35.26
		Max.	5.57	4.77	5.74	4.75	8.50	7.18	8.58	7.90	7.64	5.83	6.38	6.98	49.22
Bainbridge	42	Mean	2.77	2.38	3.29	3.13	3.76	3.71	4.97	3.84	3.16	3.19	3.03	3.19	40.42
		Min.	.73	1.18	1.73	2.07	.67	.82	.68	1.59	.50	1.45	1.13	1.15	27.22
		Max.	5.01	4.48	5.09	5.14	8.28	6.62	12.89	8.67	10.22	7.75	9.01	6.10	50.06
Delhi	28	Mean	2.76	2.39	2.97	3.20	4.17	3.99	5.07	4.07	3.47	3.29	3.57	2.96	41.91
		Min.	.95	1.05	1.58	1.77	1.34	1.56	1.31	1.08	.50	1.08	1.40	.75	32.35
		Max.	5.13	4.78	7.15	5.48	6.49	6.26	8.24	10.16	9.63	9.45	6.66	6.40	51.94
Roxbury	37	Mean	3.15	2.69	3.53	3.61	3.96	4.10	4.35	3.76	3.78	3.41	3.64	3.15	43.13
		Min.	1.04	1.20	1.65	1.45	1.33	1.38	1.25	.88	.36	1.36	1.37	1.19	32.90

1/ For reference only

for which these data were available was plotted on a basin map and iso-lines of average annual snowfall were then drawn as shown on plate 7.

12. MONTHLY PRECIPITATION. Monthly variation as well as areal distribution of rainfall in the Delaware River basin are indicated by a study of the mean monthly precipitation records for 18 rainfall stations, uniformly distributed throughout the basin, and for which long-term precipitation records are available. For each of the 18 stations the available data include monthly rainfall totals for the period of record and an average monthly rainfall computed for the period 1930 to 1952. Based on a review of these data, shown on table M-3 and plotted on plate 8, the following conclusions and generalizations are noted:

a. The highest average monthly rainfall occurs during July and August.

b. The lowest average monthly rainfall may occur during either February or October.

c. The greatest extremes of precipitation are experienced during the period of July to September, both as to deficiency of rainfall causing droughts and excessive rainfall associated with tropical storms causing major floods.

d. More uniform rainfall can be expected during the months of November through May; that is, the monthly rainfall is less likely to deviate from the long-term average rainfall for any of these months.

13. STORMS OF RECORD. The great flood producing storms of record which have occurred over the Delaware River basin are listed in table 4 and discussed in subsequent paragraphs.

TABLE M-4
STORMS OF RECORD

Storm Period	Average Precipitation over Basin (inches)
7-11 Oct 1903	6.20
20-24 Aug 1933	6.90
6-10 Jul 1935	3.70
16-19 Mar 1936	2.70
17-21 Sep 1938	6.00
19-23 May 1942	2.90
18-19 Aug 1955	4.50

14. Storm of 7-11 October 1903. A tropical barometric low joining a stagnating extratropical cyclone located off the coast of North Carolina on 8 October resulted in heavy rainfalls over New Jersey, New York and Pennsylvania. The added influence of the tropical disturbance quickly modified the cool, dry air to the rear of the cyclone and spread maritime tropical air northwards and westwards ahead of the low center, producing a convergence line over the area during the night of 8 October. Rain continued to fall until the afternoon of the 9th when it ended abruptly. As the convergence line dissipated, the extratropical disturbance remained stationary off the Carolina coast until 11 October, producing little or no rain along the Atlantic coast during the last two days of the storm period. An isohyetal pattern for the storm period 7-11 October is shown on plate 9. The heaviest rainfall center in the basin occurred in the upper reaches of the Delaware. A total of 10.20 inches of precipitation was recorded at Port Jervis, New York.

15. Storm of 20-24 August 1933. A hurricane disturbance reached the Virginia-Carolina coast early on 23 August. Meanwhile a Canadian polar high had moved into the eastern Great Lakes region, preceded by a weak cold front that dissipated off the east coast on the 21st. This high reinforced the westerly flow north of the disturbance and seemingly prevented the tropical disturbance from curving to the northeast. The disturbance took on extratropical characteristics over Pennsylvania on 24 August and was caught in the circulation of the new extratropical flow moving from the northwest on the 25th. Light showers occurred on the 23d and increased to generally heavy rains as the tropical disturbance moved through the area. An isohyetal pattern for this storm, as it occurred in the basin, is shown on plate 10. The heaviest precipitation, 15.98 inches, experienced in the Delaware basin was recorded at Peekamoose, New York. A second center occurred in the Brandywine basin where 9.2 inches of rainfall was recorded at Coatesville, Pennsylvania.

16. Storm of 6-10 July 1935. The normal eastward movement of a meteorological disturbance emanating from Minnesota on 5 July was retarded by a high pressure area of cold air centered in northern Canada. By early morning on 8 July the low pressure area had moved over southern New York, causing a series of severe thunderstorms along the front. Heavy precipitation occurred in the Lehigh and Schuylkill basins where 9.30 inches and 10.30 inches of rainfall were recorded at Bethlehem and Pottsville, respectively. Plate 11 shows the isohyetal pattern of the July 1935 storm as it occurred over the Delaware River basin.

17. Storm of 16-19 March 1936. During the period 9 to 22 March four distinct storm centers passed over the northeastern part of the United States. Two of these major disturbances on 11-12 and 17-18 March caused floods in the Delaware basin. On 10 March a Gulf

disturbance was centered off the Georgia coast and moved northeastwards with increasing intensity. By 12 March this disturbance crossed Virginia, Pennsylvania and New York accompanied by heavy precipitation over the eastern part of the United States with heavy secondary centers in the Catskills and the Pocono Mountains. This precipitation fell on a snow cover having a water equivalent of from 2 to 4 inches over most of Pennsylvania, New Jersey and southern New York. With regard to the amount and extent of precipitation this storm was notable but not extraordinary; in general, it stands out only as a major contributing factor to the greater flood that was to follow. An outstanding low pressure area emanating from the Gulf States passed over Pennsylvania and New Jersey on the 19th and was accompanied by generally heavy precipitation over the whole area affected by floods. Flood producing rainfall was recorded on 17 and 18 March. The total precipitation for the period 16 to 19 March is shown on the isohyetal map, plate 12. This second storm was of sufficient magnitude and extent to rank with the great northern storms, and together with the antecedent precipitation caused major flooding throughout the entire Delaware basin. The heaviest rainfall center in the basin occurred in the Pocono Mountains where 7.58 inches were recorded at Stroudsburg, Pennsylvania.

18. Storm of 17-21 September 1938. During the period 12-16 September continental disturbances, low pressure centers, moving along the regular paths eastward across Ohio and the St. Lawrence valleys brought 1 to 2 inches of rainfall over the Delaware basin. There was no appreciable runoff from this rainfall, and the absorptive capacity of the ground was greatly depleted, which resulted in ideal conditions for heavy runoff during the second storm, a hurricane, which followed. The second storm period began with light showers on the 17th, increased in extent and intensity through the 19th, and culminated with the heavy precipitation on the 20th and 21st which accompanied the passing of the hurricane. Although this storm was centered in the New England states it caused some flooding in the Delaware basin. The storm pattern as indicated by the isohyetal map of the Delaware basin for the storm period 17-21 September is shown on plate 13. The heaviest rainfall in the basin occurred in the vicinity of Trenton, where 9.55 inches were recorded at the Trenton number 2 station.

19. Storm of 19-23 May 1942. The rainfall period began on the 19th as a cold front, from an occluding low centered north of the Great Lakes, entered northwestern Pennsylvania where its normal progress was blocked by a moderately strong high pressure system that had become stationary off the New Jersey coast. During the subsequent 2-1/2 day period the front lay across Pennsylvania from northeast to Southwest, with but minor change in position, while small stable waves traveling northeastward along the front produced intermittent rains along both sides of this quasi-stationary frontal system. By the 22d a low pressure system, which had developed in the Carolinas, had moved

into northwestern Pennsylvania. It caused heavy precipitation as the warm moist current from the Atlantic curved northwestwards about an upper cold cyclonic circulation. The storm traveled generally northeastward across eastern Pennsylvania and into New York. The heaviest precipitation in the Delaware basin occurred on a line from the headwaters of Schuylkill River northeastward to the upper Delaware basin, where 8.57 inches were recorded at Honesdale, Pennsylvania. An isohyetal map for the storm of 19-23 May 1942 is shown on plate 14.

20. Storm of 18-19 August 1955. Hurricane "Diane" crossed the North Carolina coast on 17 August and proceeded northwestward to Lynchburg, Virginia. It then curved northeastwards on the night of the 17th passing over eastern Pennsylvania and southern New Jersey on the 18th and 19th. Rainfall amounts associated with this tropical disturbance were generally heavy, with the greatest amounts occurring in the vicinity of the hurricane path. The continued inflow of tropical air, plus orographic lifting over the foothills of Pennsylvania and southern New England, combined to produce record rainfall in southeastern Pennsylvania, New York and southern New England on the 18th and 19th of August. Hurricane "Connie," which preceded "Diane" by almost a week, resulted in more or less saturated soil conditions and relatively high base flows in streams throughout the Delaware basin. Consequently, runoff from the precipitation associated with hurricane "Diane" was much greater than would have been normally expected. Plate 15 is a map of the basin on which has been drawn the isohyetal pattern for the storm of 18-19 August, the precipitation associated with hurricane "Diane." The heaviest rainfall centers were located over the headwater drainage areas of Brodhead and Pocono Creeks and in the headwaters of the Little Schuylkill River, above Tamaqua, Pennsylvania, where 11.11 inches of precipitation were recorded at Pecks Pond, Pennsylvania, and 10.03 inches at Coaldale, Pennsylvania.

21. PERIODS OF SUBNORMAL PRECIPITATION. In spite of its favorable location in an area of reasonably adequate precipitation, the Delaware basin has experienced extended periods of subnormal precipitation some twelve times in the period of record. An indication of the severity and general distribution of the subnormal precipitation is given in table M-5 and plate 16. Table M-5 gives the rainfall deficiencies in inches below normal and the number of consecutive months of deficient precipitation for selected stations in the basin during six of the periods for which detailed records are available. The average annual precipitation and 85 percent of normal rainfall are shown for the available record from 1900 to 1957 for the Commonwealth of Pennsylvania and the States of New Jersey and Delaware on plate 16. Because of the paucity of climatological data prior to 1888, when the collection and publication of these data by the U. S. Weather Bureau was begun, discussions of droughts that occurred prior to 1888 are omitted.

TABLE M-5

DEPARTURES FROM NORMAL RAINFALL AT SELECTED STATIONS IN THE DELAWARE RIVER BASIN

Station	Drought Year:	1908	1909	1914	1922	1930	1941	1957
	Consecutive Months:	3	5	5	6	8	4	5
					(In inches)			
Allentown, Pa.		-	-	-	- 8.91	-14.30	-15.31	-10.15
Doylestown, Pa.		-	-	-	-14.76	-17.12	-12.91	-16.38
Pottsville, Pa.		-	-	-	- 9.50	-18.99	-11.94	-
Reading, Pa.		- 5.77	-10.81	- 8.58	- 6.71	-14.41	-10.16	-10.14
Mauch Chunk, Pa. *		- 4.21	-12.55	- 4.80	-10.81	-16.81	- 5.55	-
Shawmont (Philadelphia, Pa.)		- 5.27	- 9.16	- 7.13	- 9.98	-10.63	- 6.16	- 9.50
West Chester, Pa.		- 6.48	-13.46	-	-11.75	-16.72	-16.12	-10.25
Lansford, Pa.		-	-	-	-10.09	-18.33	- 5.43	-
George School, Pa.		-	-	- 9.11	- 4.68	-11.03	+ 1.84	-12.58
Quakertown, Pa.		-	-	-	- 6.47	-13.21	-13.19	-13.47
Liberty, N.Y.		- 3.21	- 9.70	- 6.01**	- 4.01**	- 5.29**	- 5.85**	-
Oneonta, N.Y.		- 3.52	- 9.11	- 5.76	- 5.64	- 5.89	- 5.06	-
Port Jervis, N.Y.		- 3.83	-12.46	- 4.06	- 5.58	- 3.08	- 7.46	- 8.16

* Also referred to as Jim Thorpe
** At Jeffersonville

22. 1895. The drought of 1895 extended through six months, June through November, with a total rainfall of about 16 inches or some six inches below the normal for the period. Because rainfall deficiencies were most severe during the growing season, extensive agricultural damage was experienced.

23. 1904. Subnormal rainfall was experienced throughout the basin from October through December. The drought was most serious in the southern counties of the basin where total deficiencies for the period ranged from four to five inches. As a result of the drought grasslands and meadows turned brown, and winter wheat did not mature properly.

24. 1909. The period of subnormal rainfall extended through five months, July to November inclusive. July of that year ranks as one of the driest Julys of record and for the North Atlantic states the average deficiency was somewhat over two inches, which is about 50 percent of normal monthly precipitation. In August, rainfall on the Delaware basin was less than one-third the normal amount; the average deficiency for the month was about 3.25 inches, making the total shortage for the two months, July and August, nearly six inches. Though the precipitation was nearly normal for the month of September, the ground was so dry in the basin that none of the water found its way into the streams. Subnormal rainfall continued through October and November, bringing total deficient rainfall amounts in the basin to about 10 or 11 inches.

25. 1914. Subnormal rainfall generally occurred in two periods which were divided by two months, July and August, of near normal precipitation. During May and June the average deficiency for the lower portion of the basin was about 40 percent of normal precipitation. Soil became so dry as to check crop growth. Following this drought period the basin experienced near normal rainfall during July and August. Subnormal rainfall then continued through September, October and November causing widespread agricultural damages. The average deficiency for this latter period was about 3-1/2 to 4 inches, bringing the total deficiency for the drought period to about five to six inches.

26. 1922. In general, the period of subnormal rainfall extended from August through the end of the year. Though the drought did not become so severe as to affect crops as seriously as had happened in some other years, the water supply in the eastern part of Pennsylvania was more critical than it had been at any time during the 50 years prior to November 1922. Total amounts of deficiency in precipitation for the period varied from 10 to 11 inches in the Schuylkill and Brandywine basins to 4 to 5 inches in the upper Delaware basin. Corn yield was very much reduced, pastures and meadows were widely ruined, springs and streams went dry and many farmers had to haul water from

distant sources. The drought was ended by near normal rainfall during December.

27. 1930. Insofar as can be determined from records of the past one hundred years, this drought stands without precedent for duration and deficiency of precipitation. Although this drought developed during the last six months of 1930, by the end of June there was already an accumulated rainfall deficiency of five inches or more in the middle and upper Schuylkill River and middle Lehigh River basins. During the next four months, ending in October, the accumulated deficiency in this dry region increased to 15 inches or more. The average rainfall deficiency for the State of Pennsylvania during these four months was 8.10 inches or 53 percent of the normal precipitation. Small streams and ponds, shallow wells and thousands of springs dried up completely. In many sections water for domestic use was hauled long distances.

28. 1941. One of the most recent periods of drought occurred in 1941 and was caused by eight months of deficient precipitation. The accumulated rainfall deficiency for the period was 8.5 inches in the Delaware River basin. In general, deficient precipitation was recorded for all months February through October except for June and July, for which precipitation was slightly above normal.

29. 1957. The year was characterized by a prolonged summer dry spell that had its most pronounced effect in the southern portion of the basin. The drought began with an extremely dry May which was followed by nearly normal rainfall in June. Deficient precipitation was reported throughout the basin from July through early October when general and sustained rainfalls brought relief to the drought area. In general, the deficiency in precipitation for the basin during the drought period varied from 12 inches in the southern part of the basin to about 6 inches in the headwaters.

30. COMPARISON OF STORM RAINFALL. The August 1955 flood was the greatest of record in the Delaware River basin. Prior to August 1955 the October 1903 storm produced the greatest flood of record on the Delaware River. The storms of October 1903 and August 1955 are examples of heavy precipitation associated with tropical disturbances which produce extraordinary floods. Rainfall during September 1903 was very light, averaging two inches below normal. Excessive rainfall during the first week of October was climaxed in the middle part of the Delaware River basin with a heavy downpour from 8 October through 10 October. A total of 15 to 16 inches of rain fell in an area centered on Paterson, New Jersey, just east of the basin, during this storm. Prior to the August 1955 storms, below normal precipitation conditions were general in the Delaware River basin. During July, precipitation averaged 60 to 70 percent below normal in the basin. Dry conditions continued in August until heavy rains associated with the progression of hurricane "Connie" occurred on the 12th and 13th.

These heavy rains, with scattered centers of 11- to 12-inch totals in portions of eastern Pennsylvania, resulted in only minor rises in most of the streams due to the dry soil conditions and because of low flow in the river channels and the low state of reservoirs and natural lakes. The rains on the 12th and 13th, however, saturated the ground and filled stream channels and lakes. This condition was followed by the high intensities of precipitation during hurricane "Diane" on 17-20 August. Rainfall depth within the Delaware basin for the period of 72 hours in the 17-20 August storm was approximately equal to the total depth for the period of 96 hours during the October 1903 storm.

31. The storm of 19-23 May 1942, characterized by intense precipitation over the upper reaches of the Lehigh and Lackawaxen Rivers, is of particular interest because of its relatively high intensity of rainfall not associated with tropical disturbances and its location within the Delaware River basin. According to the Hydrometeorological Section of the U. S. Weather Bureau the pattern of a convergence storm of this type can be used as a prototype storm pattern with the center transposable to the middle and lower part of the Delaware River basin. This storm pattern transposed would be hydrologically more critical than tropical hurricane types such as the August 1933 storm, which would be restricted to a concentrated center over the steeper slopes of the Catskill Mountains, or to the August 1955 storm, which would produce extremely heavy rains near the New Jersey coast and rainfall potentialities diminishing with distance inland from the coastline.

32. DEPTH-AREA-DURATION RELATIONS. Rainfall data for several major storms in and near the general area of the Delaware River basin are shown by maximum depth-area-duration curves on plate 17. Table M-6 shows the area-depth relations for these storms within the basin.

TABLE M-6

MAXIMUM RAINFALL DEPTH-AREA DATA FOR TOTAL STORM PERIOD

Storm	Drainage Area 10 sq. mi.		Drainage Area 100 sq. mi.		Drainage Area 1,000 sq.mi.		Drainage Area 10,000 sq. mi.	
	Maximum Storm Depth (in.)	Max. Depth Delaware Basin (in.)	Maximum Storm Depth (in.)	Max. Depth Delaware Basin (in.)	Maximum Storm Depth (in.)	Max. Depth Delaware Basin (in.)	Maximum Storm Depth (in.)	Max. Depth Delaware Basin (in.)
18-19 August 1955	19.6	11.5	19.0	11.4	17.1	10.4	10.8	5.3
17-21 September 1938	17.1	10.0	15.1	9.9	13.8	8.9	11.3	6.6
7-11 October 1903	15.5	10.5	14.4	10.0	12.4	9.2	8.9	6.9
20-24 August 1933	15.9	14.0	13.9	10.3	11.6	8.8	9.0	6.9
6-10 July 1935	14.2	10.7	13.4	9.0	11.1	7.7	7.2	4.7
19-23 May 1942	8.6	8.5	8.2	8.1	7.3	7.2	5.4	3.9
16-19 March 1936	7.9	7.1	7.5	7.0	7.2	6.1	6.3	3.4
10-12 December 1952	-*	5.0	-*	4.8	-*	4.2	-*	2.8
Basin Project **	-	8.5	-	8.1	-	7.2	-	5.1

* Storm study not made.

** Basin Project Storm is the May 1942 rainfall pattern transposed over the Delaware basin.

SECTION III - RUNOFF

33. RUNOFF DATA. The U. S. Geological Survey is the Federal agency primarily responsible for the collection and tabulation of surface and ground water data. These data are published annually in U.S.G.S. Water Supply Papers. The U.S.G.S. data and earlier streamflow data published by Department of Forests and Waters, Commonwealth of Pennsylvania, were the principal sources of information on runoff used in the preparation of this appendix. Additional data on river stages were secured from the U. S. Weather Bureau's annual publications "Daily River Stages" and from miscellaneous reports of the Delaware River Joint Toll Bridge Commission. Details of surface runoff hydrographs for individual storms were derived by the Corps of Engineers from stage hydrographs and discharge rating curves or tables supplied by the U. S. Geological Survey.

34. RIVER STAGE AND STREAM GAGING STATIONS AND PERIODS COVERED BY RECORD. Throughout the periods of record 157 gages have been operated within the basin, and at the present time 49 of these gages have been discontinued. A total of 108 recording and nonrecording river stage and stream gaging stations are now operated within the Delaware River basin. Of these, 90 are rated to permit conversion of stage data to discharge, and the remaining 18 stations are for river stage only. The locations of all river stage and stream gaging stations are shown on plate 18. The period of record and the type of river stage and stream gaging stations within the basin are given on plate 19.

35. MONTHLY RUNOFF. Mean monthly flows for the periods of record for the Lehigh River at Bethlehem, Schuylkill River at Philadelphia, Brandywine Creek at Wilmington, and Delaware River at Port Jervis, Riegelsville and Trenton are shown graphically on plate 20. Table M-7 gives the monthly runoff data in cubic feet per second per square mile (csm) for the 42 years of record at Trenton, New Jersey. The average monthly runoff for the period of record is 1.77 csm. The greatest average monthly runoff is 3.40 csm, occurring during April; and the lowest is 0.84 csm, occurring in September. The maximum mean monthly flow of record, 9.31 csm, occurred in March 1936, and the minimum of 0.21 csm in September 1932.

36. MAJOR FLOODS AT SELECTED STATIONS. Peak stages and discharges published by the U.S.G.S. for major floods at several selected stations throughout the Delaware River basin are given in table M-8. In most cases the discharges were determined by the extension of rating curves. Included in this table are available data on historical floods at these stations. A brief description of those floods which are of particular interest is given in the following paragraphs.

TABLE M-7

MONTHLY RUNOFF OF DELAWARE RIVER AT TRENTON

CUBIC FEET PER SECOND PER SQUARE MILE

YEAR	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1914	0.57	1.71	1.50	1.12	1.84	3.00	4.96	2.44	0.77	0.87	0.66	0.47
1915	0.30	0.34	0.60	3.44	3.43	1.66	1.81	1.32	0.74	1.26	1.81	1.03
1916	0.82	0.89	1.59	2.30	2.07	1.93	5.33	1.65	1.74	1.52	0.76	0.51
1917	0.51	0.51	1.23	1.85	0.84	3.21	2.72	1.28	2.49	1.35	0.84	0.53
1918	0.74	1.66	0.61	0.68	2.94	3.90	3.04	1.59	1.12	0.49	0.40	0.48
1919	0.65	0.75	1.28	1.91	1.15	3.37	2.85	2.56	0.90	1.56	1.29	0.78
1920	0.81	2.65	1.97	0.76	0.50	5.28	4.06	1.65	1.09	1.49	1.33	1.04
1921	1.57	1.97	3.47	1.54	1.12	4.87	2.52	1.96	0.58	0.85	0.60	0.41
1922	0.49	1.49	2.35	0.82	1.69	4.13	3.56	1.76	2.40	1.39	0.62	0.62
1923	0.44	0.34	0.35	1.29	0.92	4.18	2.88	2.21	0.80	0.40	0.38	0.47
1924	0.59	0.69	2.34	3.02	1.16	1.71	4.80	3.13	1.08	0.78	0.42	0.42
1925	2.34	0.60	0.95	0.53	4.06	2.57	1.90	1.53	0.74	0.90	0.95	0.88
1926	0.80	2.38	2.10	1.31	1.94	2.80	3.02	1.08	0.81	0.41	1.01	0.94
1927	1.54	3.74	1.49	1.69	2.24	4.03	1.74	2.40	1.40	0.82	1.33	1.53
1928	3.62	4.08	4.28	1.85	2.65	2.04	3.69	2.91	2.97	3.52	2.03	1.50
1929	0.68	0.58	0.75	1.21	1.33	4.08	4.43	2.75	0.95	0.59	0.48	0.57
1930	1.20	1.65	1.82	1.88	1.82	3.02	2.19	1.14	1.40	0.60	0.28	0.33
1931	0.24	0.36	0.46	0.55	0.78	2.09	3.21	2.44	1.39	1.74	0.60	0.41
1932	0.26	0.29	0.73	2.03	1.99	1.54	3.68	1.56	1.13	0.62	0.34	0.21
1933	1.50	4.02	1.26	1.52	1.63	3.19	4.55	1.60	0.75	0.51	2.87	3.34
1934	1.15	1.01	1.18	2.29	0.77	2.24	3.80	1.76	0.91	0.68	0.53	1.70
1935	1.60	1.65	3.01	2.09	1.39	3.34	2.17	1.69	0.77	2.56	0.64	0.63
1936	0.44	3.31	2.11	2.14	1.07	9.31	3.88	1.27	0.98	0.41	0.43	0.37
1937	0.54	1.04	2.03	3.69	2.79	1.82	3.86	2.34	1.43	0.90	1.02	0.80
1938	1.61	2.03	1.85	2.14	2.54	2.25	2.41	1.37	1.41	2.68	1.83	2.73
1939	1.15	1.60	3.85	1.49	3.67	3.80	4.12	1.26	0.57	0.36	0.35	0.23
1940	0.52	1.12	0.85	0.66	0.70	2.78	8.01	2.36	1.70	0.79	0.41	1.42
1941	0.57	2.12	2.16	1.69	1.39	1.80	3.33	0.81	0.74	0.66	0.57	0.26
1942	0.22	0.47	1.14	1.22	1.41	3.48	2.27	3.02	1.77	0.85	1.93	1.64
1943	2.49	2.48	2.79	2.73	2.62	3.85	2.45	3.67	1.76	0.62	0.36	0.25
1944	0.76	2.43	0.71	0.87	0.99	3.01	3.66	1.65	1.01	0.48	0.30	0.46
1945	0.37	0.68	1.52	1.47	1.35	5.71	2.44	2.99	2.11	3.78	2.02	1.79
1946	1.91	2.67	2.21	2.56	1.05	3.62	1.24	3.09	2.64	1.14	0.76	0.56
1947	0.82	0.64	0.65	1.87	1.74	2.92	4.01	4.60	2.07	2.95	1.24	0.64
1948	0.35	2.26	1.09	0.82	1.67	5.26	3.93	3.33	1.94	1.11	0.77	0.33
1949	0.35	0.89	1.66	4.91	2.86	1.98	2.46	2.40	0.76	0.50	0.34	0.36
1950	0.39	0.68	1.66	2.12	1.96	3.38	3.66	2.01	1.70	1.06	0.65	0.63
1951	0.42	2.20	3.92	2.74	4.11	3.46	4.35	1.19	1.12	1.20	0.96	0.57
1952	0.79	3.72	2.80	3.64	2.71	3.69	5.42	3.36	1.94	1.79	0.86	1.45
1953	0.46	1.93	3.94	3.32	2.87	3.86	3.94	2.94	1.03	0.49	0.32	0.38
1954	0.33	0.89	2.74	1.10	2.24	2.66	2.19	2.63	0.72	0.28	0.25	0.53
1955	0.36	2.16	2.15	1.58	1.43	3.47	2.16	0.99	0.76	0.28	5.02	1.00
Mean	0.89	1.64	1.84	1.87	1.89	3.34	3.40	2.14	1.31	1.12	0.96	0.84
Max.	3.62	4.08	4.28	4.91	4.11	9.31	8.01	4.60	2.97	3.78	5.02	3.34
Min.	0.22	0.29	0.35	0.53	0.50	1.54	1.24	0.81	0.57	0.28	0.25	0.21

All flows adjusted for storage and diversion.

Avg. Monthly Runoff for 42 years - 1.77
Max. Mean-Monthly Runoff - 9.31 (March 1936)
Min. Mean-Monthly Runoff - 0.21 (Sept. 1932)

TABLE M-8

MAJOR FLOODS AT SELECTED STATIONS

Year	Date	W.Br.Delaware R. at Hale Eddy D.A.-593 sq.mi. Gage Ht. (feet)	Peak Q (cfs)	E.Br.Delaware R. at Fishs Eddy D.A.-783 sq.mi. Gage Ht. (feet)	Peak Q (cfs)	Delaware R. at Port Jervis D.A.-3076 sq.mi. Gage Ht. (feet)	Peak Q (cfs)	Delaware R. at Trenton D.A.-6780 sq.mi. Gage Ht. (feet)	Peak Q (cfs)	Lehigh R. at Bethlehem D.A.-1279 sq.mi. Gage Ht (feet)	Peak Q. (cfs)	Schuylkill R. at Philadelphia D.A.-1893 sq.mi. Gage Ht. (feet)	Peak Q (cfs)	Brandywine Cr. at Chadds Ford D.A.-287 sq.mi. Gage Ht. (feet)	Peak Q (cfs)
1955	18-20 Aug	12.67	16,000	15.29(1)	27,400(1)	23.91(2)	233,000(2)	20.83(3)	329,000(3)	23.38	91,300	14.32	90,100	13.89(4)	17,800(4)
1942	19-23 May	14.52	21,900	17.18	34,900	17.76	140,000	13.35	161,200	23.47	92,000	12.40	61,400		
	9 Aug											13.10	71,500	14.8	16,800
1938	12-22 Sep	15.59	25,600	18.21	41,000	14,95	101,000	11.45	125,000			10.66	37,700		
1936	12-18 Mar	14.22	25,900	19.21	46,000	17.55	137,400	16.66	227,000	17.04	55,700	11.62	48,400		
1935	9-10 Jul	12.62	19,000					11.74	129,000	18.53	63,700	14.10	82,000		
1933	20-24 Aug	12.31	16,000	20.6	53,300	15.03	102,000	12.66	147,000	18.70	64,800	14.7	96,200	14.01	14,800
1920	5 Mar									12.0	26,200			15.00	17,200
1903	7-11 Oct	20.3*	46,000	23.6*	70,000	23.1	205,000	20.7	295,000(5)						
1902	1- 2 Mar								252,000(6)	22.8	88,000	14.8	98,000		
1901	16 Dec								242,000(6)						
1869	4 -15 Oct								175,000(6)	20.3	73,600	17.0	135,000		
1862	5 - 8 Jun								225,000(6)	21.2	78,600				
1850	2 Sep									16.6	54,000	16.42	125,000		
1841	8 Jan								256,000(6)	19.7	70,300	13.6	71,500		
1839	26 Jan									12.3	32,900	15.8	114,000		
1786	4 - 6 Oct								177,000(6)	14.4	42,500				

* Gage height established from flood marks.

(1) No contribution from area above Downsville Dam.
(2) No contribution from areas above Downsville and Wallenpaupack Dams.
(3) No contribution from areas above Downsville, Wallenpaupack, and Neversink Dams.
(4) Brandywine Creek at Wilmington, D.A. = 314 sq. mi.
(5) Published by Dept. of Forests and Waters, Commonwealth of Pennsylvania, 1942.
(6) At Stockton, N.J., D.A.=6,656 sq.mi.; Report of Geological Survey of N.J. 1894 & 1902.

37. <u>Flood of January 1839</u>. After a period of unusually low temperatures during January, a warm rain commenced on the night of 25 January and increased to a violent intensity. The rain continued until the afternoon of 26 January when the weather again became cold. The total quantity of rainfall was about 3-1/2 inches. Schuylkill River at Philadelphia experienced an estimated peak flow of approximately 114,000 c.f.s., with a crest stage above Fairmount Dam of more than 10 feet. The streams were swollen with rushing water carrying immense masses of ice. Bridges and property fell under the combined force of ice and current. Wharves along the Schuylkill from Fairmount to Grays Ferry were damaged, and large quantities of coal and wood were swept off by the flood. On the Delaware River all the bridges from Easton to Trenton were carried away. The ice in Lehigh River came down in a mass tearing away 75 feet of the embankment of the basin of the Pennsylvania Canal. The water rose about 15 feet above low watermark. The water in Brandywine Creek rose from 20 to 22 feet and all the bridges on the stream, except one highway bridge and one railroad bridge, were swept off. All dams were broken, and all mills and factories for many miles up the Brandywine were damaged.

38. <u>Flood of January 1841</u>. The flood of 8 January occurred after a period of intense low temperatures throughout the basin. All streams throughout the area were frozen over, including Delaware River at Philadelphia. The temperature at Philadelphia averaged about 6° above zero for the period 2-6 January. On 6 January the temperature increased rapidly to about 40°F., accompanied by heavy rains which lasted for two days. The persistent rain and thaw quickly broke up the ice in the rivers and the onrush of runoff from upstream areas produced the largest flood experienced on Delaware River to that time. (Estimated peak discharge - 256,000 c.f.s. at Trenton, over 35 feet above low water.) The heavy ice blocks and rushing water did tremendous damage to bridges and dams. Not a bridge was left on Lehigh River, and destruction of property was great. Extensive bridge and property damage occurred on the Schuylkill between Reading and Philadelphia. At Fairmount Dam water reached a height of eight feet above the dam.

39. <u>Flood of September 1850</u>. A violent rainstorm accompanied by heavy thunder occurred on 2 September over the Schuylkill and Lehigh River basins. The rain that fell amounted to about 3-3/4 inches which was somewhat less than the amount that occurred during a storm the preceding July, but the September rainfall occurred in less than half the duration of the earlier storm. The resulting flood was the highest ever known up to that time with an estimated peak of 125,000 c.f.s. on Schuylkill River at Philadelphia. Eleven highway bridges were swept away on the Schuylkill within a short distance of 41 miles between Phoenixville and Mohrsville. The flood rose to the height of 11 feet above Fairmount Dam. Every bridge on the Schuylkill from Tamaqua to Port Clinton was swept away and approximately 50 persons

lost their lives in that area. The Schuylkill canal was damaged, which caused stoppage of coal shipments for four weeks. The flood on Lehigh River caused considerable damage mainly to bridges and to the Lehigh canal near Allentown, Pennsylvania. Lehigh River at Bethlehem rose to a height of about 17 feet. Delaware River at Easton rose to between 17 and 18 feet above normal.

40. Flood of June 1862. The flood of 5-8 June 1862 was the most severe in the Lehigh River basin recorded up to that time. It was caused by the greatest storm on the Lehigh since 1841 which produced an estimated 78,600 c.f.s. peak discharge at Bethlehem, Pennsylvania. At Easton, the lower portion of the city, bordering on Lehigh and Delaware Rivers, was inundated and the floodwater reached the second story levels of the dwellings. All highway bridges on the Lehigh between Easton and Jim Thorpe (formerly Mauch Chunk) were swept away. The whole town of Weissport was washed away with but three houses left out of about 300. Loss of life was high. Much damage was done on Brodhead Creek and McMichaels Creek, and Stroudsburg suffered severely. All the bridges on Brodhead Creek except the railroad bridge were destroyed and some damage occurred to the Delaware, Lackawanna and Western Railroad. Delaware River at Delaware Water Gap was three feet lower than the previous record high stages in the flood of 1841. The water was 27 feet high on Lehigh River at the dam at Jim Thorpe, six feet higher than in the flood of 1841. The headwaters area of Schuylkill River sustained some damage, though small in comparison to that in the Lehigh basin. Three bridges of the Reading Railway between Port Clinton and Schuylkill Haven were destroyed, and navigation on Schuylkill River was interrupted temporarily.

41. Flood of October 1869. The "Northeaster" flood of 4-6 October caused considerable damage on Schuylkill River and remains the flood of record with an estimated 135,000 c.f.s. peak discharge at Philadelphia, Pennsylvania. An unparalleled drought of so serious a character that the water supply of the city of Philadelphia was greatly diminished was followed closely by a freshet of unprecedented violence. Bridges were carried away, factories and dwellings were inundated, and Fairmount, Flat Rock and other dams, which a few days previously had been high and dry, were completely submerged by the waters that dashed over them with terrific violence. The flood was caused by rain that fell during 2 and 3 October. The amount that fell during this period was one-tenth as much as had fallen for one year previously, or 4.7 inches, at Philadelphia, Pennsylvania. The total storm rainfall over the basin reached approximately 6-3/4 inches. On 5 October crest stage over Fairmount Dam, Philadelphia, reached 11-1/2 feet, or 1/2 foot higher than ever previously recorded. Schuylkill River at Reading, Pennsylvania, rose 22 feet above normal level, or three feet less than during the 1850 flood. Delaware River at Philadelphia rose 20 feet above normal level. Lehigh River at Bethlehem rose 20 feet above low watermark, 15 inches short of the 1862 flood

height. At Wilmington, Delaware, it was the greatest flood on the Brandywine River since 1839.

42. Flood of October 1903. The flood of 7-11 October occurred as a result of a hurricane associated storm which centered east of the upper Delaware River basin. Most of the basin above Trenton was in severe flood and records were established that remained unbroken until 52 years later in August 1955 when flood crests several feet higher were recorded in much of the Delaware River. Flood flows in the upper basin were exceedingly high in 1903 and flood stages reached on the East and West Branches of Delaware River at Fishs Eddy and Hale Eddy, respectively, still remain the maximum of record.

43. Flood of August 1933. The storm of 21-25 August was of the tropical hurricane type which came inland at Norfolk, Virginia, crossed the length of the Susquehanna River basin, and continued northeastward across New York State. The storm produced high runoff causing serious flooding on various streams along the western and northern portions of the Delaware River basin. Schuylkill River at Reading reached a stage of 21.4 on 24 August which is slightly below the alltime record of 22.17 feet on 23 May 1942. A large area was flooded in the southern portion of the city. Basements were filled and the first floors of hundreds of homes and business places were inundated by flood waters. All of the towns along the river from Reading to Philadelphia suffered some degree of flood damage. In the upper portion of the basin major flooding was confined to Neversink River and East Branch of Delaware River. At Fishs Eddy, on the East Branch of Delaware River, flood stage reached 20.6 feet, which is the second highest in 45 years of record.

44. Flood of July 1935. The flooding was caused by several severe localized thunderstorms which occurred during the period 6 to 9 July. Torrential rains on the 7th and 8th of July, centered along the divide of the Susquehanna and Delaware Rivers in southern New York, caused considerable flooding along several minor tributary streams of the West Branch of Delaware River. Heavy thunderstorms occurred in eastern Pennsylvania on 9 July and flooded the Lehigh and Schuylkill Rivers, causing considerable damage when these streams rose as much as 20 feet above bank-full stage during the night of 9 and 10 July. Perkiomen Creek, a tributary of Schuylkill River, rose as much as 20 feet in some places, causing considerable damage to summer cottages along the banks.

45. Flood of March 1936. Until 25 February the season was typical of winter, the temperature was low and streamflow at the minimum for the season. On 25 February there was a marked rise in temperature, with but little precipitation throughout the basin. The thaw extending from 25 February to 10 March was moderate and discontinuous in upstream areas in New York and Pennsylvania, but somewhat more

intense and unbroken in New Jersey in the basin below Riegelsville, New Jersey. It was not of sufficient degree to remove entirely the snow cover or the frost from the ground. Snow cover on 10 March, expressed as water content in inches, ranged over the basin from 5 to 8 inches in the headwaters in New York and Pennsylvania, to zero below Trenton, New Jersey. There were two major storms, the first occurring on 11-12 March and the second on 17-18 March, followed by a minor storm at the end of the storm period on 21 March. Runoff from the second storm was greater than that from the first storm on the main stem. On the tributaries in the southern part of the basin in Pennsylvania and New Jersey, the runoff from the first storm was the greater. At a few places in the central part of the basin there was approximately the same runoff from each major storm.

46. Flood of September 1938. The central path of the tropical storm of 17-21 September was east of the Delaware River basin and, consequently, there was a tendency for precipitation in the basin to increase from west to east. Runoff from the storm was generally marked by a single peak, and maximum stages occurred during the afternoon or evening of 21 September. Total direct runoff ranged from 2.4 inches in the northern and western part of the basin to 4.3 inches in the southeastern part of the basin, and from 43 to 59 percent of the total runoff occurred during the 24-hour period ending in the afternoon of 22 September. Southern New Jersey experienced severe flooding, particularly in Trenton where the overflow of Assunpink Creek flooded several large factories and caused considerable damage.

47. Flood of May 1942. During the first three weeks of May 1942, frequent heavy rains were general over the Delaware River basin. Particularly heavy storms occurred during the period 20-23 May, which culminated in crest stages on most streams approximating or exceeding those of recent history. While many sections were seriously inundated by the flood, the greatest devastation occurred in the Lackawaxen River basin, particularly at Honesdale, Pennsylvania, where the central section of the town was inundated to a depth of 5 or 6 feet. The resulting flood on Schuylkill River at Reading was the third highest since 1757. On Lehigh River it was the second highest in 156 years of record. Estimates of flood damage amounted to approximately $15,000,000. Thirty-three persons lost their lives, thirty-five bridges were washed out, and ten small dams failed.

48. Flood of August 1955. Hurricane "Connie," which passed over the basin on 12-13 August, encountered the extremely dry conditions which prevailed through July and early August. In general most of the rains were absorbed by the dry soil and produced comparatively little runoff. The rains, however, served to saturate the ground and fill stream channels and reservoirs. The stage, therefore, was set for floods from the storm that followed. Most of the recharge moisture was still in the soil when hurricane "Diane" began a few days later,

so that the precipitation had little opportunity to infiltrate the soil or to be delayed otherwise and quickly entered the river channels. The high intensity of rainfall during "Diane" caused floods with remarkable rapidity and of unprecedented proportions. Most of the drainage area above Trenton was in major flood. Flood flows were particularly high in Lackawaxen River, reaching a stage of 20.6 feet at Hawley, Pennsylvania on 19 August, compared to 20.1 feet in May 1942. Bush Kill at Shoemakers, Pennsylvania, had more than four times the previous maximum flood flow. Brodhead Creek, which flows through Stroudsburg, Pennsylvania, before joining Delaware River, rose to unprecedented heights. At Minisink Hills, near Stroudsburg, the stage was 29.9 feet, more than twice the previous stage of record. There was a major flood in the Lehigh River basin. It was principally an upper basin flood but all along the main river, except at Lehighton and Bethlehem, Pennsylvania, new record highs were experienced. At the latter point the May 1942 flood was approximately equalled. In the Schuylkill River basin the larger flows were in the northern tributaries, but some new highs were established along the main river. The heaviest flooding was concentrated in the narrow drainage area of Little Schuylkill River above Port Clinton, Pennsylvania. A stage of 11.1 feet was reached at Tamaqua, Pennsylvania, 3.15 feet above the stage of 7.95 feet in May 1942. Major flooding was general along Delaware River, exceeding the previous most disastrous flood of 1903 at all points above Trenton. Below Trenton high tides abetted and prolonged the flood waters.

49. MAXIMUM FLOODS OF RECORD. Peak stages and discharges for the 18-20 August 1955 flood and the previous maximum floods of record are tabulated for gaging stations on Delaware River and its principal tributaries in table M-9.

50. PERIODS OF SUBNORMAL RUNOFF. Periods of from 1 to 3 months of subnormal runoff occur annually within the Delaware River basin, but due to their short duration cause only minor inconveniences and damages in restricted localities. Periods of subnormal runoff from 5 to 8 months in length were experienced generally throughout the basin following the periods of deficient precipitation listed in paragraph 6. Since streamflow records are not available prior to 1905, information on deficient runoff is confined to those periods following the droughts of 1908, 1909, 1914, 1930-31, 1941 and 1957. Monthly runoff values and comparisons with the means for the periods of record are shown for Delaware River at Port Jervis, New York, and Trenton, New Jersey in plate 21. A general discussion of the severity of the deficient runoff periods is given in subsequent paragraphs.

51. 1908. Streamflow generally over the Delaware River basin was considerably below normal during the last seven months of the year. Runoff for Delaware River at Port Jervis for June through December averaged 35 percent of the normal.

TABLE M-9

MAXIMUM FLOODS OF RECORD

Stream	Station	Zero of Gage (feet above msl)	Drainage Area (sq.mi.)	Previous Maximum of Record			August 1955		
				Date	Peak Stage (feet)	Max.Discharge (cfs)	Date	Peak Stage (feet)	Max.Discharge (cfs)
W.Br. Delaware R.	Delhi, N.Y.	1,345.29	142	21 Sep 38	8.81	8,940	18 Aug	7.19	4,660
	Hale Eddy, N.Y.	946.46	593	10 Oct 03	20.3 (1)	46,000	19 Aug	12.67	16,000
E.Br. Delaware R.	Harvard, N.Y.	1,008.06	443	22 Sep 38	16.93	31,400	19 Aug	10.34	7,590
	Fishs Eddy, N.Y.	950.96	783	9 Oct 03	23.6 (1)	70,000	19 Aug	15.29	27,400
Delaware R.	Barryville, N.Y.	600.22	2,023	23 May 42	23.19	105,000	19 Aug	26.40	130,000
	Port Jervis, N.Y.	415.35	3,076	10 Oct 03	23.1	205,000	19 Aug	23.91	233,000
	Montague, N.J.	369.93	3,480	10 Oct 03	35.5 (1)	234,000	19 Aug	35.15	250,000
	Belvidere, N.J.	226.43	4,535	10 Oct 03	28.6 (1)	220,000	19 Aug	30.21	273,000
	Riegelsville, N.J.	125.12	6,328	10 Oct 03	35.9 (1)	275,000	19 Aug	38.85	340,000
	Trenton, N.J.	7.77	6,780	11 Oct 03	20.7	295,000	20 Aug	20.83	329,000
Lackawaxen R.	Hawley, Pa.	869.00	290	23 May 42	20.1 (1)	50,000	19 Aug	20.6 (1)	51,900
Neversink R.	Woodburne, N.Y.	1,180.00	113	26 Nov 50	11.19	22,000	18 Aug	6.63	4,650
	Oakland Valley, N.Y.	632.00	222	26 Nov 50	12.62	23,300	19 Aug	12.74	23,800
	Godeffroy, N.Y.	459.66	302	26 Nov 50	11.79	20,000	19 Aug	12.49	33,000
Paulins Kill	Blairstown, N.J.	335.86	126	22 Sep 38	7.56	4,480	19 Aug	11.12 (1)	8,750
Pequest R.	Pequest, N.J.	398.78	108	14 Mar 36	4.97	1,810	19 Aug	3.87	1,110
Lehigh R.	Tannery, Pa.	1,042.06	322	22 May 42	16.51	29,600	19 Aug	22.2 (1)	58,300
	Bethlehem, Pa.	208.45	1,279	23 May 42	23.47 (1)	92,000	19 Aug	23.38	91,300
Musconetcong R.	Bloomsbury, N.J.	274.83	143	10 Oct 03	8.00	6,960	19 Aug	6.95	4,430
Tohickon Cr. Nr	Pipersville, Pa.	258.96	97.4	9 Aug 42	10.48	13,700	18 Aug	11.26	16,000
L.Schuylkill R.	Tamaqua,Pa.	817.48	42.9	22 May 42	7.95	4,310	18 Aug	11.10	7,790
Schuylkill R.	Berne, Pa.	310.65	355	23 May 42	15.00 (1)	26,900	19 Aug	15.73	29,400
	Pottstown, Pa.	117.86	1,147	23 May 42	20.15	50,800	19 Aug	17.98	42,300
	Philadelphia, Pa.	5.74	1,893	4 Oct 1869	17.0	135,000	19 Aug	14.32	90,100
Brandywine Cr.	Wilmington, Del.	68.23	314	5 Mar 20(2)	15.0 (2)	17,200(2)	19 Aug	13.89	17,800

(1) Estimated by U. S. Geological Survey from flood marks.
(2) Brandywine Creek at Chadds Ford, Pa. D.A.=287 sq.mi.

52. 1909. Low flow conditions began during the latter part of July following the driest July since 1888. Subnormal flows continued throughout the basin until mid-December when rainfall of from 1 to 4 inches occurred over the upper branches of the Delaware and Susquehanna Rivers. Runoff during the six-month period averaged 20 percent of normal. Water supplies for many cities and towns, although used with the utmost economy, were scarcely sufficient for domestic use and were insufficient for protection against fire.

53. 1914. Following a period of deficient precipitation beginning in February, runoff decreased generally throughout the basin and averaged 35 percent of normal from June through December. By October streams and lakes were of lower levels than any ever shown in official records prior to this time, and the memory of the "oldest inhabitant" recollected no lower water in Delaware River just above Trenton in over forty years. Although precipitation averaged two inches above normal during December, runoff was 25 percent of the normal for the month and not until January, when precipitation again averaged 2 to 3 inches above the mean, did streamflows return to normal. The deficiency in precipitation and streamflow was sufficient to make the shortage in water supply keenly felt during November and December. Wells, streams and lakes were very low and in some cases dried up entirely.

54. 1930-31. This extended period of subnormal runoff occurred during the worst drought in some 80 years of record. Runoff on the main stem of Delaware River for the entire two-year period averaged 80 percent of normal and runoff deficiencies between 25 and 30 percent below normal were experienced in Schuylkill and Lackawaxen Rivers. At Trenton average monthly flows were below the mean for 11 consecutive months, June 1930 to April 1931, and total flow for the period was 54 percent of the normal. The effects of deficient precipitation and streamflow were not felt until the latter part of November 1930 when springs and wells began to go dry and thousands or rural families were compelled to haul water for domestic use. Drought conditions prevailed throughout the winter months. Although more nearly normal precipitation occurred during January through April it was only enough to keep the topsoil in fair condition and did not penetrate deeply enough to help the wells and springs. By November 1931 both surface and ground water supplies were drastically deficient, and many wells and springs were reported dry for the first time in their history. While drought conditions continued in certain sections of the basin until the fall of 1934, generally streamflows returned to normal by the end of 1931.

55. 1941. Subnormal runoff began in January 1941 and continued through February 1942. Streamflow for Delaware River at Trenton averaged 63 percent of normal for the 14-month period. Drought conditions became severe during the last of May following four months of deficient

precipitation. The spring season, March-May, was one of the three driest of record in New Jersey since 1885. Deficient precipitation, low ground water conditions, and lack of soil moisture during the spring produced an extreme fire hazard generally throughout the basin. Many thousands of acres of timber and pastureland were burned-over in New York and New Jersey. Although nearly normal precipitation occurred in June and July it brought only temporary relief, and by October serious drought conditions again prevailed. Streams and water supplies continued low in many localities, and many farmers hauled water great distances. The October runoff at Trenton, 1,500 c.f.s., was only 25 percent of the normal and the second lowest in 44 years of record. The rains of November and December were sufficient to return streamflows to near normal early in 1942, and to replenish soil moisture and water supplies.

56. 1957. Streamflow began declining generally throughout the basin during the latter part of May. Monthly runoff for Delaware River at Trenton was below the mean from June through December, with the exception of October. Water levels in wells and lakes declined at a greater than average rate, and by July some U.S.G.S. observation wells in New Jersey reached new record lows. Streamflow continued to be deficient until late November when many streams ceased to flow while others reached record lows. Storage in reservoirs, serving the smaller communities in the basin, became critically low and in some cases drastic conservation measures were necessary. The power-water storage in Wallenpaupack Reservoir reached critical recreational levels, and practically no water was released from this reservoir during the period 25 July to 2 September. Serious water shortages occurred in northeast New Jersey during October and November where storage in several large reservoirs, supplying some 1,500,000 persons was reduced to about one-third capacity. The reservoir supplying the city of Orange, New Jersey, went dry on 30 October. Two New York City reservoirs located in the basin, Pepacton and Neversink, were reduced by the end of November to only 37 percent of active storage capacity above elevations of maximum reservoir depletion. Heavy rainfall in December produced spectacular improvement in water supplies throughout the basin and usable reservoir contents increased from 25 to 60 percent of capacity during the month. Streamflow in certain localities was excessive in contrast to deficient flow for the previous six to eight months.

57. FLOOD PROFILES. Data on peak flood stages and high watermarks for Delaware River and its principal tributaries were compiled and used in defining profiles for various record floods. The most complete coverage of peak stages was for the flood of 18-20 August 1955. Immediately following the flood survey parties made field investigations and established sufficient high watermarks to define closely the high water profiles in urban areas and to define adequately but with a lesser degree of accuracy the profiles in rural areas.

The 1955 flood profiles together with profiles of other record floods for Delaware River, including the lower bay reach, Lehigh River, and Schuylkill River are shown on plates 22 to 26 inclusive.

SECTION IV - EVAPORATION AND INFILTRATION LOSSES

58. GENERAL. The primary concern of the present study with evaporation is in the realm of water losses from reservoir surfaces. The design and operation of reservoirs must allow for the effects of evaporation on the dependable minimum yields of proposed projects. This section presents available evaporation data, indicates the average annual heat budget and water balance of the basin, and shows the average monthly variation of losses.

59. FREE WATER SURFACE EVAPORATION. Maps of average annual and May-September (growing season) evaporation from free water surfaces throughout the basin were compiled by the U. S. Weather Bureau using Class A pan evaporation and related meteorological data. These are reproduced on plates 27 and 28. The U. S. Geological Survey made a study of free water surfaces in the Delaware River basin. 3/ Some of the results of that study are summarized in table M-10.

TABLE M-10
FREE WATER SURFACE EVAPORATION

Source	Area	Annual		May - Sep.		Oct. - April	
	Square Miles*	1,000 ac.-ft.	inches	1,000 ac.-ft.	inches	1,000 ac.-ft.	inches
Lakes, ponds, and reservoirs	83	135	30.6	95	21.5	40	9.1
Swamps	147	251	32.0	174	22.2	77	9.8
Streams	64	107	31.3	75	22.0	32	9.3
Total	294	493	31.5**	344	22.0**	149	9.5**

* Excludes areas of salt marsh, bays, and estuary.
** Weighted average.

		Average Annual Loss 1,000 ac.-ft.
Total (all sources)	=	15,632
From free water surfaces	=	493
From ground and vegetation	=	15,139 (or 22.8 inches)

3/ Data from J. Stuart Meyers, U.S.G.S.

60. Evapotranspiration is the term applied to loss of water by evaporation to the atmosphere from ground, free water surfaces, and from vegetation. In the subsequent discussion amounts of evaporation from the ground and vegetation are treated as a single quantity. Transpiration is the process by which plants absorb water through their root systems, transmit it internally to their leaves whence it is evaporated through pores (stomata) in the leaf surfaces. There are varying opinions concerning the role of transpiration in the life functions of plants. There is little difference of opinion, however, on the factors governing local plant transpiration rates. These are:

a. Availability of moisture to plant roots,
b. The heat budget of the area, and
c. The type of vegetation and soil.

The availability of soil moisture will have a limiting effect on transpiration since a plant cannot transpire water at a rate higher than can be sustained by the supply available to it at its roots. When more water is available than is needed, the transpiration rate is governed mainly by the heat budget of the plant and is known as "potential evapotranspiration." Potential evapotranspiration will vary with the type of ground and vegetation because of different types of ground surface and variations in root and vascular structure among different plants. Interactions of the grounded plants on the local heat budget also affect evapotranspiration. Color, texture, structure and density of cover affect vegetative albedo and emissivity to short and long wave radiation, which are the most prominent factors in the heat budget of the area. Since plants rarely have an overabundance of soil moisture except during and immediately after rains, evapotranspiration normally proceeds at less than "potential" rate. Few data on evapotranspiration measurements are available for this area. However, from the average annual heat budget, data on average seasonal amounts of precipitation, runoff and evaporation from open water surfaces and lakes, average seasonal values of evapotranspiration may be deduced.

61. ANNUAL HEAT BUDGET. The average annual solar (shortwave) radiation incident upon the Delaware River basin is approximately 120,000 Langley (ly).4/ Based on an average annual air temperature of 51° F. over the basin and an emissivity of atmosphere = 0.76, the annual downward longwave radiation is about 210,000 ly. The average overall albedo of the basin is approximately 0.15. Of the shortwave radiation, approximately 15 percent is reflected and 85 percent is absorbed. The estimated total absorbed radiation is therefore 0.85 x 120,000 + 210,000 = 312,000 ly. Of this amount the basin loses 280,000 ly by outward longwave radiation. Thus the net absorbed radiation is 32,000 ly. In the course of a year the net advection of heat

4/ Langley - standard unit of measurement for heat flux = 1 gram-calorie per square centimeter, abbreviated ly.

in the area may be assumed to be zero and, under the assumption of an average constant temperature, there is no net change in the heat content of the basin. The net absorbed radiation is therefore chargeable to evapotranspiration. Based on latent heat of evaporation of water, 1 ly of heat will evaporate approximately 0.0007 inches of water. Thus the expected annual evapotranspiration in the Delaware basin is on the order of 32,000 x 0.0007 or about 22.4 inches.

62. ANNUAL WATER BALANCE. The value of evapotranspiration loss computed in the preceding paragraph is in close agreement with the average annual precipitation-runoff balance as seen by the following data for the basin:

	Average Annual inches
Precipitation	44
Runoff	21
Loss	23

If it is assumed that the average annual losses to and withdrawals from ground water are essentially in balance, then this loss of 23 inches may be ascribed entirely to evapotranspiration. Average monthly values of precipitation, runoff, and losses are shown in plate 29. The monthly heat budget and monthly changes in ground water storage would be needed to compare the observed monthly losses with thermal estimates. However, little work has been done along these lines in this area, and a detailed thermal and water balance study of the basin is beyond the range of capabilities for the present report.

63. INFILTRATION AND BASE STREAMFLOW. While the water balance from a general climatic viewpoint is of importance in precipitation-water yield studies, detailed water control and operation studies require intimate details of the behavior of surface and subsurface waters during periods of storm rainfall-runoff. The reconstruction of past flood flows from precipitation data and the synthesis of design floods utilize water balance factors from the relations of storm rainfall to runoff during and immediately following the storm period. The water balance involved in such cases is the hour-by-hour account, as the storm progresses, of the losses to temporary and permanent surface retention and absorption, and of the gains from ground water releases. For purposes of the present study certain conventions were adopted in the development of unit-hydrographs which permitted estimation of infiltration rates during periods of rainfall excess based on a residual runoff volume after determination of a base flow release from ground water. Paragraph 97 discusses the determination of rainfall excesses, losses, and infiltration rates. Average hourly infiltration rates were found to vary from 0.06 to 0.26 inch per hour depending on the

geologic character of the various portions of the basin. This variation is shown on plate 30.

64. The primary application of infiltration information is in the area of estimation of flood runoff from storm rainfall as described above. It is generally recognized that infiltration rates vary considerably during nonflood periods. The methods of hydrologic analyses associated with the study of such periods, however, depend largely on observed runoff at stream gaging stations and place no dependence on the short-term water balance between precipitation and runoff as in the case of floods. The particular application of infiltration rates in connection with agricultural needs is fully described in Appendix K.

SECTION V - BASIC HYDROLOGY STUDIES

65. SCOPE OF BASIC STUDIES. In planning for the comprehensive development of water resources for the river basin certain basic information and analyses are required in order to evaluate properly the potential of these resources. The information referred to here consists primarily of basic data on physical characteristics, precipitation, runoff, evaporation and infiltration which was covered in the first four sections of this appendix. Analyses based on combinations of these data comprise the basic hydrologic "tools" needed by the planner in the field of comprehensive water resources development. The studies necessary to develop these hydrologic "tools" for the Delaware River basin are presented in subsequent paragraphs of this section and include the following:

- Mass Curves
- Flow Duration Curves
- Frequency Analyses of Peak Flows
- Frequency of Low Flows
- Unit Hydrographs
- Streamflow Routing
- Reservoir Routing
- Surface Water Availability

66. MASS CURVES. Mass curves of stream discharge were prepared for every stream gage in the Delaware River basin and for some outside the basin. The basic data used were published records of mean monthly streamflow. In all cases mass curve tabulations were prepared from the observed flows for the actual period of record. For key stations, however, additional mass curve tabulations were prepared using flows corrected for storage and diversion, and where necessary, extended to a period of standard length by correlation with stations having longer histories. The standard period covered 32 water-years, 1923-1954 inclusive. The beginning of the adopted period was taken as early as possible to sample the low flow years without excessive extension of short term records. The end of the adopted period was the date of the latest complete data available at the time these analyses were being made. A sample mass curve for Delaware River at Trenton is shown on plate 31. The application of mass curves in water availability studies is discussed in the section on surface water availability studies.

67. FLOW DURATION CURVES. From data furnished by the U. S. Geological Survey mean daily-flow duration curves were prepared for the following 24 stations:

East Branch Delaware River at Fishs Eddy, N. Y.
West Branch Delaware River at Hale Eddy, N. Y.
Lackawaxen River at Hawley, Pa.
Wallenpaupack Creek at Wilsonville, Pa.
Mongaup River near Mongaup, N. Y.
Delaware River at Port Jervis, N. Y.
Neversink River at Oakland Valley, N. Y.
Bush Kill at Shoemakers, Pa.
McMichaels Creek at Stroudsburg, Pa.
Paulins Kill at Blairstown, N. J.
Lehigh River at Tannery, Pa.
Lehigh River at Bethlehem, Pa.
Musconetcong River near Bloomsbury, N. J.
Tohickon Creek at Pipersville, Pa.
Delaware River at Trenton, N. J.
Assunpink Creek near Trenton, N. J.
Neshaminy Creek near Langhorne, Pa.
North Branch Rancocas Creek at Pemberton, N. J.
Perkiomen Creek near Frederick, Pa.
Perkiomen Creek at Graterford, Pa.
Schuylkill River at Pottstown, Pa.
Schuylkill River at Philadelphia, Pa.
Brandywine Creek at Chadds Ford, Pa.
Maurice River at Norma, N. J.

Sample curves for Bethlehem, Port Jervis and Trenton are shown on plate 32. The data used in the development of these curves were observed flows and therefore reflect existing influences of storage and diversion. Application of these curves is found mainly in studies of hydroelectric power potentials as described in the appendix on that subject. Minimum yields of various subareas were determined from the 95 percent value on the flow-duration curve. These minimum yields were used to develop net project yields. Some additional flow-duration data and regionalized curves for general use have been developed by the U. S. Geological Survey.5/

68. FREQUENCY ANALYSES OF PEAK FLOWS. Streamflow data were secured from U. S. Geological Survey records for 79 stations in the Delaware River basin having 10 years or more of record. Nine of these stations were not suitable for frequency analysis due to upstream regulation and, therefore, were not used. Plate 33 shows graphically the number of stations and available lengths of record. The station at Trenton, New Jersey (drainage area of 6,780 sq. mi.) had the longest complete record, 55 years. The records for the stations on Delaware River at Port Jervis, Montague, Belvidere, Riegelsville and

5/ Studies completed in July 1958 by the U. S. Geological Survey in connection with preparation of a report on Water Resources of the Delaware River and Its Service Area.

Trenton were adjusted for the regulatory effect of Lake Wallenpaupack. An average natural flow versus observed flow relationship was developed for each of these stations by routing changes in reservoir contents during selected storms. These derived relations were used as the basis for adjustments for regulation throughout the period of record.

69. Nomenclature. The term "frequency curve" as used here refers to the cumulative frequency distribution of the logarithms of the annual peak flows. Because the curve represents cumulative frequencies in descending order of flow magnitude, the probability scale gives the percent chance that an annual peak will be equalled or exceeded, and is sometimes designated "exceedence frequency." The terms "percent chance of occurrence" and "exceedence frequency" are used interchangeably in the present context. The following symbols designate the variables used in the frequency analyses of peak flows and the generalized flood frequency study.

m	-	Mean of logarithms of annual peak flows, log Q_m.
$\bar{s}$	-	Standard deviation, which is the root-mean-square deviation of the logarithms of the annual peak flows.
$m + \bar{s}$	-	Logarithms of annual peak flow with 15.9% exceedence frequency, log $Q_{(m + \bar{s})}$.
Q_m	-	Annual peak flow, c.f.s., having 50% exceedence frequency.
$Q_{(m + \bar{s})}$	-	Annual peak flow, c.f.s., having 15.9% exceedence frequency.
D.A.	-	Drainage area, square miles.
L	-	Length of main stream, miles.
S_{st}	-	Average slope of main stream, ft./mile (harmonic mean of stream slope computed as in unit hydrograph study).
P_r	-	Average annual precipitation, inches.
$\bar{R}^2$	-	Coefficient of determination adjusted for degrees of freedom; a measure of level of accuracy of the estimated record.

All values of m and $\bar{s}$ used in the generalizations are the adjusted values shown on table M-11 under columns headed "Based on Extended Record."

TABLE M-11

SUMMARY OF PEAK FREQUENCY STATISTICS

No.	Stream	Location	Drainage Area	Based on Record Yrs.	Based on Record m	Based on Record $\bar{S}$	Based on Extended Record Equiv. Yrs.	Based on Extended Record m	Based on Extended Record $\bar{S}$	Based on Extended Record $\bar{R}^2$
1	E.Br.Delaware R.	Margaretville, N.Y.	163	19	3.795	.236	45	3.786	.273	.738
2	Platte Kill	Dunraven, N.Y.	34.7	14	3.186	.233	42	3.162	.251	.698
3	Mill Brook	Arena, N.Y.	25	18	3.228	.264	36	3.142	.306	.601
4	Tremper Kill	Shavertown, N.Y.	33	18	3.180	.222	44	3.172	.255	.729
5	Terry Clove Kill	Pepacton, N.Y.	14.1	18	2.921	.260	38	2.907	.288	.567
6	E. Br.Delaware R.	Downsville, N.Y.	373	13	4.072	.193	51	4.071	.221	.918
7	E.Br. Delaware R.	Harvard, N.Y.	443	20	4.157	.215	50	4.145	.251	.881
8	Beaver Kill	Craigie Clair, N.Y.	82	18	3.701	.170	44	3.617	.209	.853
9	Willowemoc Creek	Livingston Manor, N.Y.	63	18	3.544	.194	46	3.438	.242	.936
10	L. Beaver Kill	Livingston Manor, N.Y.	19.8	31	3.134	.191	39	3.120	.189	.475
11	Beaver Kill	Cooks Falls, N.Y.	241	42	3.970	.223	48	3.930	.224	.484
12	E.Br.Delaware R.	Fishs Eddy, N.Y.	783	51	4.404	.183	54	4.420	.196	.727
13	E.Br.Delaware R.	Delhi, N.Y.	142	18	3.613	.170	40	3.608	.193	.615
14	L.Delaware R.	Delhi, N.Y.	49.8	18	3.313	.148	44	3.306	.169	.719
15	Trout Creek	Cannonsville, N.Y.	49.5	15	3.340	.176	21	3.342	.180	.170
16	Cold Spring Brook	China, N.Y.	1.51	21	1.926	.226	32	1.919	.233	.392
17	Oquaga Creek	Deposit, N.Y.	66	15	3.373	.120	31	3.378	.127	.486
18	W.Br.Delaware R.	Hale Eddy, N.Y.	593	43	4.182	.169	49	4.187	.170	.456
19	Callicoon Creek	Callicoon, N.Y.	111	16	3.701	.205	25	3.680	.207	.259
20	Tenmile R.	Tusten, N.Y.	45	10	3.199	.265	45	3.068	.261	.828
21	Delaware R.	Barryville, N.Y.	2023	15	4.765	.174	51	4.728	.166	.946
22	W.Br.Lackawaxen R.	Prompton, Pa.	59.7	11	3.493	.173	22	3.479	.170	.262
23	Dyberry Creek	Dyberry, Pa.	63.2	12	3.595	.268	27	3.576	.263	.362
24	Middle Creek	Hawley, Pa.	78.4	12	3.562	.247	25	3.532	.254	.329
25	Lackawaxen R.	W. Hawley, Pa.	206	17	3.748	.185	37	3.766	.194	.571
26	Lackawaxen R.	Hawley, Pa.	290	20	4.094	.270	40	4.037	.275	.643
27	Delaware R.	Port Jervis, N.Y.	3076	43	4.856	.208	52	4.863	.210	.786
28	Neversink R.	Curry, N.Y.	68	12	3.741	.177	36	3.680	.239	.669
29	Neversink R.	Neversink, N.Y.	92.5	12	3.846	.235	40	3.708	.289	.781
30	Neversink R.	Woodburn, N.Y.	113	16	3.865	.214	37	3.777	.254	.660
31	Neversink R.	Oakland Valley, N.Y.	222	25	3.954	.215	41	3.918	.209	.701
32	Neversink R.	Godeffroy, N.Y.	302	16	4.005	.160	40	3.931	.193	.730
33	Delaware R.	Montague, N.J.	3480	16	4.957	.229	51	4.896	.221	.964
34	Bush Kill	Shoemakers, Pa.	117	36	3.336	.266	43	3.334	.258	.481
35	Flat Brook	Flatbrookville, N.J.	65.1	32	3.207	.296	41	3.200	.295	.440
36	McMichaels Creek	Stroudsburg, Pa.	65.3	27	3.180	.174	42	3.201	.180	.607
37	Paulins Kill	Blairstown, N.J.	126	34	3.279	.227	43	3.274	.229	.510
38	Pequest R.	Pequest, N.J.	108	34	2.848	.138	39	2.846	.139	.250
39	Beaver Brook	Belvidere, N.J.	36.2	32	2.700	.219	37	2.696	.214	.262
40	Delaware R.	Belvidere, N.J.	4535	33	4.965	.204	53	4.968	.192	.905
41	Lehigh R.	Stoddartsville, Pa.	91.7	13	3.582	.396	43	3.478	.383	.766
42	Lehigh R.	Tannery, Pa.	322	42	3.851	.289	49	3.852	.288	.755
43	Wild Creek	Hatchery, Pa.	16.8	15	2.720	.330	29	2.696	.318	.386
44	Aquashicola Creek	Palmerton, Pa.	76.7	16	3.384	.287	25	3.369	.282	.242
45	L. Lehigh Creek	Allentown, Pa.	80.8	10	2.938	.190	29	2.919	.191	.446
46	Jordan Creek	Allentown, Pa.	75.8	11	3.433	.256	40	3.400	.263	.717
47	Lehigh R.	Bethlehem, Pa.	1279	47	4.361	.260	52	4.370	.266	.571
48	Delaware R.	Riegelsville, N.J.	6328	43	5.014	.190	54	5.026	.192	.927
49	Tohickon Creek	Pipersville, Pa.	97.4	20	3.828	.215	32	3.815	.210	.327
50	Delaware R.	Trenton, N.J.	6780	55	5.030	.187				
51	Assunpink Creek	Trenton, N.J.	89.4	32	3.132	.182	35	3.132	.180	.149
52	Crosswicks Creek	Extonville, N.J.	83.6	16	3.177	.251				
53	Neshaminy Creek	Langhorne, Pa.	210	22	4.029	.283	27	4.018	.282	.153
54	N.Br. Rancocas Cr.	Pemberton, N.J.	111	20	2.911	.184				
55	Schuylkill R.	Pottsville, Pa.	53.4	13	3.357	.328	28	3.311	.322	.404
56	Schuylkill R.	Reading, Pa.	880	12	4.255	.155	28	4.274	.170	.398
57	Schuylkill R.	Pottstown, Pa.	1147	28	4.313	.223	47	4.301	.202	.824
58	Perkiomen Creek	Graterford, Pa.	279	42	4.125	.260	45	4.125	.260	.320
59	Ridley Creek	Moylan, Pa.	31.9	23	3.119	.278	32	3.104	.284	.393
60	Chester Creek	Chester, Pa.	61.1	24	3.501	.258	31	3.490	.264	.347
61	Christina R.	Coochs Bridge, Del.	20.5	12	3.168	.114				
62	Red Clay Creek	Wooddale, Del.	47	12	3.330	.133				
63	Brandywine Creek	Chadds Ford, Pa.	287	44	3.809	.222	45	3.810	.222	.097
64	Shellpot Creek	Wilmington, Del.	7.46	10	3.112	.267				
65	Salem Creek	Woodstown, N.J.	14.6	15	2.974	.460				
66	Leipsic Creek	Cheswold, Del.	9.2	12	2.263	.191				
67	Maurice R.	Norma, N.J.	113	23	2.771	.288				
68	Manantico Creek	Millville, N.J.	22.3	22	2.362	.299				
69	Mantua Creek	Pitman, N.J.	6.75	15	2.097	.467				
70	White Clay Creek	Newark, Del.	87.8	10	3.587	.114				

70. Basic Frequency Statistics for Individual Stations. The basic statistics, the mean (m) and the standard deviation ($\bar{s}$), were computed analytically for each individual gaging station in accordance with Beard's method.6/ Straight line frequency curves were drawn on log-probability paper with slopes equal to the standard deviations and with the means at 50 percent probability. The annual peaks were also plotted on the same sheet for graphical comparison with the statistical curve with plotting positions computed from the formula

$$P = 100\ (1\text{-}0.5^{\ 1/N}),$$

where P = Plotting position (probability)
and N = Number of years of record.

This formula was used to compute the probability of the largest event of each record, and the others are linearly interpolated to the 50 percent position. Figure 1 on plate 34 shows the frequency curve derived analytically from the basin statistics (curve A) and also the plotting position points of annual flood peaks on Lehigh River at Tannery.

71. Adjustment for Longer Record. The annual peaks for the period of record of the short term stations were correlated with those for comparable years at a station with a long term record. The (m) and ($\bar{s}$) of the short term station were then adjusted by the correlations. To make the adjustments of the means and the standard deviations for all stations it was necessary first to select the key "long term station" and "base station" in the basin. The entire basin was divided into seven areas and a "base station" selected for each area. These "base stations" were first adjusted to the "long term" station at Trenton and then used for adjustment of the statistics of the shorter record stations. In some cases it was found desirable to correlate short record stations with several "base stations" in order to determine which pair of stations had the best correlation for the common period of record. The adjusted frequency curve for Lehigh River at Tannery after correlation with the "base station" on Lehigh River at Bethlehem is shown in figure 1, plate 34 (curve B). The mean (m) and standard deviation ($\bar{s}$) based on the original record, the adjusted (m) and ($\bar{s}$), and the coefficient of determination ($\bar{R}^2$) for the 70 stream gaging stations used in this study are tabulated in table M-11.

72. Classification of Flow Frequency with Regard to Storm Type. A comparison of the adjusted frequency curves which plot as straight lines on logarithmic probability paper (assuming normal distribution and zero skew coefficient) with the "eye-fit" curve defined by flows

6/ Beard, Leo R., Statistical Methods in Hydrology, Office, Chief of Engineers, Department of the Army, July 1952.

from the plotting position formula shows considerable variation in the highest floods of record. This is illustrated in figure 2, plate 34, for Lehigh River at Tannery which shows the percent chance of occurrence in any given year from plotting point as 1.6 percent for a discharge of 58,300 c.f.s., while the corresponding value from the statistical curve is 0.067 percent. These frequencies represent recurrence intervals of about 63 years and 1,500 years, respectively. In order to explain this large variance in frequencies between the two curves, a study was made of storm causes in the Delaware River basin. This study indicates that most of the extremely high floods and a limited number of moderate or low floods result from hurricane-type storms and consequently they differ basically from other floods experienced from other types of storms in the basin. Thus the annual flood record at any gaging station may be regarded as composed of at least two different populations which are intermingled. Basic statistical theory requires that each population be represented by a different frequency relation having a different mean and standard deviation. There are no doubt many other populations which are represented by annual peak flows at any particular gaging station. Such factors as intensity of precipitation, antecedent moisture conditions, and seasonal variations are some additional factors which would affect flow peaks. However, limitations of available basic data and the scope of the present work made it expedient at this time to consider only the two populations, hurricane and nonhurricane.

73. Station records of peak flood flow at 18 representative stations throughout the basin (selected for size of drainage area and location) were classified with respect to storm origin as either hurricane or nonhurricane events. The dates of hurricane storms, shown in table M-12, were obtained from the U. S. Weather Bureau.7/ If the annual peak flow was associated with a hurricane-type storm, then the next highest peak flow associated with a nonhurricane storm was secured to fit in the annual nonhurricane series. The Beard frequency curves for nonhurricane floods were computed analytically and plotted. The resulting relation is illustrated in figure 2 (curve C) on plate 34.

74. Since hurricanes do not occur annually in the basin, it was impossible to utilize the annual flood frequency analysis for the hurricane series. For purposes of statistical analysis it is necessary to have an array wherein the unit time period used contains at least one event of the type under investigation. On examination of hurricane events it was found that a minimum period of three years was required to satisfy this condition as can be seen from the data in table M-12. If more than one flood flow of hurricane origin occurred in a

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7/ U. S. Weather Bureau, Interim Report on Hurricane Rainfall, Hydrometeorological Service, Subproject 3, (Draft).

TABLE M-12
HURRICANE SERIES OF ANNUAL PEAK FLOWS

Lehigh River at Tannery, Pa.

Date of Hurricane: Water Year	Date of Hurricane: Month & Day	Discharge (c.f.s.): Actual	Discharge (c.f.s.): 3-Year Peak
1956			
55	19 Aug.	58,300	58,300
54	31 Aug.	840	
53			
52	2 Sept.	3,750	3,750
51			
1950			
49	29 Aug.	800	800
48			
47			
46			
45	19 Sept.	1,650	1,650
44	14 Sept.	610	
43	18 Oct.	1,080	1,080
42			
41			
1940	1 Sept.	5,570	5,570
39			
38	22 Sept.	3,960	3,960
37			
36			
35	5 Sept.	640	
34	9 Sept.	750	
33	24 Aug.	17,600	17,600
32			
31			
1930	3 Oct.	3,090	3,090
29			
28	4 Oct.	2,340	2,340
27			
26			
25			
24	30 Sept.	10,400	10,400
23			
22			
21	1 Oct.	2,850	2,850

three-year period, only the largest was used in the frequency array. Basic statistics, the mean and standard deviation were computed analytically from the hurricane flood series to obtain the hurricane flood frequency curve. An example of this type curve is shown in figure 2 (curve D) on plate 34. It is to be noted that the frequency scale of the hurricane series curve represents probability of exceedence in a three-year period. The conversion of this tri-annual curve to an annual series is discussed in the next paragraph.

75. According to probability methods, it is possible to determine the chance that a tri-annual peak flow of any frequency would have of being an annual peak flow. If P_{3y} is the probability of any given event occurring in any given three-year period, the probability that it will occur in one year, P_y, is much less and can be expressed by

$$P_y = 1-(1-P_{3y})^{1/3} .$$

The annual probabilities of five points selected from each tri-annual frequency curve were computed by the above relationship. The solution of this equation gives the values of P_y shown in table M-13 for various values of P_{3y}.

TABLE M-13
CHANCE OF ANNUAL OCCURRENCE BASED UPON
THE PROBABILITY OF TRI-ANNUAL OCCURRENCE

Tri-Annual P_{3y} (%)	Annual P_y (%)
3	1
14	5
27	10
49	20
66	30

The line of best fit for the above relation is shown in figure 2 (curve E) on plate 34.

76. GENERALIZED FLOOD FREQUENCY STUDY. Preceding paragraphs have dealt with the derivation of natural annual peak frequency curves for gaged streams in the Delaware basin. It was seen that logarithms of annual peak flows have essentially a normal distribution, permitting definition of the frequency curve with two statistics computed from the data, namely, the mean and the standard deviation. For use in planning studies it was necessary to develop a relationship between

these defining statistics of the frequency curves and some topographic features of drainage areas in the Delaware basin, first for the basin as a whole and then for various regions within the basin.

77. Three basic functions were evaluated to establish a relationship between the parameters of the frequency curve and basic topographic characteristics. All three functions purported directly or indirectly to define the 50 percent flow (Q_m) and the 15.9 percent flow ($Q_{m+\bar{s}}$) on the frequency curve. The volume index assumed a general function of the form

$$Qt = A(DA)^b, \text{ where } t = \frac{L}{\sqrt{S_{st}}} \; ;$$

the multiple regression approach assumed a general function of the form

$$Q = A\,(DA)^{b_1}\,(S_{st})^{b_2}\,(L)^{b_3}\,(P)^{b_4} \; ;$$

and the area-slope index simplified the multiple regression approach by reducing the assumed function to the form

$$Q = A\,(DA\sqrt{S_{st}})^b$$

78. Area-Slope Index. Stream length and precipitation were eliminated from the function because they were not significant in the preliminary multiple regression analyses involving drainage area, stream slope, stream length, and basin precipitation. As suggested by the relative magnitudes of the coefficients of log DA and log S_{st} (nearly 1.0 and 0.5, respectively), the relationships were modified to express m and m + $\bar{s}$ as functions of $DA\sqrt{S_{st}}$, hereafter designated as the area-slope index. The equations for the data of 70 stations were:

$$m = 0.676 + 1.057 \log (DA\sqrt{S_{st}}) \text{ and}$$

$$m + \bar{s} = 1.000 + 1.024 \log (DA\sqrt{S_{st}}),$$

with coefficients of determination of 0.90 for m and 0.89 for (m + $\bar{s}$). These equations had standard errors of estimate of about 60 percent for Q_m and 65 percent for $Q_m + \bar{s}$, which were too large for acceptance. Consequently, stratification of the data into subgroups with respect to geographical orientation of areas within the basin was examined next.

79. Regionalization. The exploratory regression analyses were based on the data for 70 stations grouped together as one large sample. Examination of plots of the data, however, indicated a tendency for the data of certain regions to fall consistently above or below the regression line. Accordingly, the data were regrouped into four populations designated as Groups A, B, C and D. All stations having 15 years of record or less were excluded to improve the degree of reliability. Areas corresponding to the four groups are delineated on the basin map, plate 35. Stream and station names and associated parameters for the gaged stations are listed by groups in table M-14.

80. As described for the grouped data of 70 stations in the preceding paragraph, the area-slope indexes were re-evaluated for each of the four groups and the main stem of Delaware River. Table M-15 shows equation constants, adjusted coefficients of determination, standard errors of estimate, and percentage ranges for one standard error on either side of the mean for each of the four groups, the main stem stations, and all 70 stations. To write any regression equation for the 50 percent flow, m, the appropriate constants are substituted in the general function

$$m = a + b \ \log (DA \sqrt{S_{st}}).$$

The same general function applies to the 15.9 percent flow by using $(m + \bar{s})$ with appropriate coefficients instead of m. These equations may be solved graphically as shown on plate 36. The lower standard errors for the stratified data indicate a distinct improvement over the 70 station grouping.

81. The area-slope index was adopted for use in the synthesis of frequency curves for ungaged areas in the Delaware River basin according to their geographical orientation with respect to areal groups (plate 35). A fifth pair of equations was adopted for construction of synthetic frequency curves for damage points on the main stem of Delaware River. Synthetic frequency curves are compared with the observed Beard curves for several selected stations on plates 42 and 43. Within the scope of the present investigation and with the parameters studied, an acceptable degree of accuracy has been achieved in the area-slope equations. It is recognized that the adopted equations may be subject to refinement at a later date if further investigation appears warranted. Pending such refinements, however, the area-slope index equations were used for the planning purposes of this study.

82. Hurricane and Nonhurricane Populations. Synthetic frequency curves constructed by the method set forth herein will be of the "mixed" variety with respect to storm classification. As discussed earlier in paragraph 72, the mixed annual peak series may be resolved into two populations according to association of the flood peak with a hurricane or nonhurricane storm event. It was further desirable,

TABLE M-14

PERTINENT DATA FOR REGIONAL ANNUAL PEAK FREQUENCY

No. (1)	Stream & Location (2)	DA (3)	log DA (4)	log S_{st} (5)	log L (6)	log P (7)	m (8)	m+s (9)	Q_m (10)	Q_{m+s} (11)	log t (12)	m+log t (13)	m+s+log t (14)	log (DA $\sqrt{S_{st}}$ (15)	DA $\sqrt{S_{st}}$ (16)	t (17)	$Q_m t$ (18)	$Q_{(m+s)} t$ (19)
	GROUP A																	
1	E. Br. Del. R. Margaretville	163.0	2.212	1.103	1.290	1.643	3.786	4.059	6,110	11,470	0.738	4.524	4.797	2.764	580	5.47	33,422	62,741
3	Mill Brook Arena	25.0	1.398	2.112	0.969	1.681	3.142	3.448	1,386	2,802	-0.087	3.055	3.361	2.454	358	0.82	1,135	2,284
4	Tremper Kill Shavertown	33.0	1.519	1.875	0.943	1.633	3.172	3.427	1,487	2,669	0.005	3.177	3.432	2.457	286	1.01	1,502	2,696
5	Terry Clove Kill Pepacton	14.1	1.149	1.951	0.706	1.633	2.907	3.195	806	1,569	-0.270	2.637	2.925	2.125	133	0.54	434	844
7	E. Br. Del. R. Harvard	443.0	2.646	0.978	1.742	1.645	4.145	4.396	13,980	24,900	1.253	5.398	5.649	3.175	1,490	17.90	250,242	445,710
8	Beaver Kill Craigie Clair	82.0	1.914	1.756	1.369	1.740	3.617	3.826	4,149	6,710	0.491	4.108	4.317	2.792	620	3.10	12,862	20,801
9	Willowemoc Cr. Livingston Manor	63.0	1.799	1.598	1.279	1.703	3.438	3.680	2,740	4,790	0.480	3.918	4.160	2.598	396	3.20	8,768	15,328
10	L. Beaver Kill Livingston Manor	19.8	1.297	1.830	0.892	1.667	3.120	3.309	1,320	2,100	-0.023	3.097	3.286	2.212	163	0.95	1,254	1,995
11	Beaver Kill Cooks Falls	241.0	2.382	1.586	1.513	1.708	3.980	4.204	9,550	16,000	0.720	4.700	4.924	3.175	1,495	5.25	50,138	84,000
12	E. Br. Del. R. Fishs Eddy	783.0	2.894	0.953	1.797	1.669	4.420	4.616	26,400	41,305	1.321	5.741	5.937	3.371	2,350	20.94	552,816	864,927
13	W. Br. Del. R. Delhi	142.0	2.152	1.291	1.398	1.618	3.608	3.801	4,060	6,349	0.752	4.360	4.553	2.798	628	5.65	22,939	35,872
14	L. Del. R. Delhi	49.8	1.697	1.705	1.158	1.628	3.306	3.475	2,021	2,985	0.306	3.612	3.781	2.549	354	2.02	4,082	6,030
16	Cold Spring Br. China	1.5	0.179	2.455	0.322	1.602	1.919	2.152	83	142	-0.906	1.013	1.246	1.407	26	0.12	10	18
18	W. Br. Del. R. Hale Eddy	593.0	2.773	1.024	1.884	1.623	4.187	4.357	15,370	22,760	1.372	5.559	5.729	3.285	1,925	23.50	361,195	534,860
19	Callicoon Cr. Callicoon	111.0	2.045	1.524	1.288	1.677	3.680	3.887	4,790	7,790	0.517	4.197	4.404	2.816	657	3.29	15,759	25,629
21	Lackawaxen R. W. Hawley	206.0	2.314	1.279	1.535	1.648	3.766	3.960	5,840	9,130	0.895	4.661	4.855	2.954	898	7.85	45,844	71,671
26	Lackawaxen R. Hawley	290.0	2.462	1.356	1.522	1.648	4.037	4.312	10,900	20,520	0.844	4.881	5.156	3.140	1,380	6.98	76,082	143,230
30	Neversink R. Woodbourne	113.0	2.053	1.631	1.452	1.692	3.777	4.031	5,990	10,795	0.636	4.413	4.667	2.869	739	4.33	25,937	46,742
31	Neversink R. Oakland Valley	222.0	2.346	1.486	1.712	1.678	3.918	4.127	8,280	13,400	0.969	4.887	5.096	3.089	1,223	9.31	77,087	124,754
32	Neversink R. Godeffroy	302.0	2.480	1.486	1.757	1.671	3.931	4.124	8,530	13,300	1.014	4.945	5.138	3.223	1,665	10.34	88,200	137,500
35	Flat Brook- Flatbrookville	65.1	1.814	1.241	1.375	1.638	3.200	3.495	1,584	3,126	0.755	3.955	4.250	2.434	271	5.69	9,016	17,784
	GROUP B																	
34	Bush Kill Shoemakers	117.0	2.068	1.574	1.369	1.648	3.334	3.592	2,158	3,909	0.582	3.916	4.174	2.855	715	3.82	8,243	14,932
36	McMichaels Cr. Stroudsburg	65.3	1.815	1.463	1.365	1.653	3.201	3.381	1,588	2,405	0.633	3.834	4.014	2.547	353	4.30	6,822	10,332
37	Paulins Kill Blairstown	126.0	2.100	1.065	1.423	1.643	3.274	3.503	1,880	3,185	0.891	4.165	4.394	2.632	428	7.78	14,628	24,782
38	Pequest R. Pequest	108.0	2.033	0.764	1.396	1.663	2.846	2.985	702	966	1.014	3.860	3.999	2.415	260	10.34	7,259	9,988
39	Beaver Br. Belvidere	36.2	1.559	1.302	1.114	1.672	2.696	2.910	497	810	0.463	3.159	3.373	2.210	162	2.90	1,441	2,349
42	Lehigh R. Tannery	322.0	2.508	1.325	1.551	1.638	3.852	4.140	7,110	13,900	0.889	4.741	5.029	3.170	1,479	7.74	55,067	107,656
44	Aquashicola Cr. Palmerton	76.7	1.885	1.279	1.350	1.633	3.369	3.651	2,340	4,478	0.710	4.079	4.361	2.523	333	5.13	12,000	22,972
47	Lehigh R. Bethlehem	1279.0	3.107	1.154	1.969	1.633	4.370	4.636	23,420	43,260	1.392	5.762	6.028	3.684	4,825	24.66	577,537	1,066,792
57	Schuylkill R. Pottstown	1147.0	3.060	0.869	1.886	1.642	4.301	4.503	20,000	31,850	1.452	5.753	5.955	3.494	3,112	28.32	566,400	901,992
	GROUP C																	
49	Tohickon Cr. Pipersville	97.4	1.989	1.024	1.362	1.643	3.815	4.025	6,532	10,600	0.850	4.665	4.875	2.501	317	7.08	46,247	75,048
51	Assunpink Cr. Trenton	98.4	1.951	0.764	1.286	1.638	3.132	3.312	1,356	2,052	0.904	4.036	4.216	2.333	215	8.02	10,871	16,451
52	Crosswicks Cr. Extonville	83.6	1.922	0.677	1.146	1.658	3.177	3.428	1,504	2,680	0.808	3.985	4.236	2.260	182	6.43	9,666	17,224
53	Neshaminy Cr. Langhorne	210.0	2.322	1.185	1.531	1.648	4.018	4.300	10,400	20,000	0.939	4.957	5.239	2.914	820	8.69	90,376	173,800
58	Perkiomen Cr. Graterford	279.0	2.446	1.138	1.453	1.633	4.125	4.385	13,340	24,270	0.884	5.009	5.269	3.015	1,035	7.66	102,131	185,811
59	Ridley Cr. Moylan	31.9	1.504	1,447	0.966	1.663	3.104	3.388	1,271	2,444	0.242	3.346	3.630	2.228	169	1.75	2,219	4,267
60	Chester Cr. Chester	61.1	1.786	1.395	1.303	1.658	3.490	3.754	3,100	5,676	0.605	4.095	4.359	2.484	304	4.03	12,487	22,863
63	Brandywine Cr. Chadds Ford	287.0	2.458	1.065	1.581	1.658	3.810	4.032	6,460	10,770	1.049	4.859	5.081	2.990	978	11.20	72,352	120,624
	GROUP D																	
54	N. Br. Rancocas Cr. Pemberton	111.0	2.045	0.869	1.253	1.658	2.911	3.095	815	1,245	0.819	3.730	3.914	2.479	301	6.59	5,372	8,207
67	Maurice R. Norma	113.0	2.053	0.723	1.204	1.643	2.771	3.059	590	1,146	0.842	3.613	3.901	2.415	260	6.95	4,101	7,966
68	Manantico Cr. Millville	22.3	1.348	1.001	0.845	1.653	2.362	2.661	230	458	0.345	2.707	3.006	1.848	71	2.21	509	1,014
71	Great Egg Harbor R. Folsom	56.3	1.751	0.723	1.255	1.653	2.439	2.683	274	482	0.893	3.332	3.576	2.113	130	7.82	2,142	3,768
72	E. Br. Wading R. Harrisville	64.0	1.806	0.836	1.322	1.667	2.581	2.803	381	635	0.904	3.485	3.707	2.224	167	8.02	3,055	5,091

Note: Refer to paragraph 5.02 g for explanation of symbols.

Stations 71 and 72 are located outside of the Delaware River basin and were used to further define Group D

TABLE M-15
SUMMARY OF CONSTANTS FOR GENERALIZED EQUATIONS BY GROUPS

Area-Slope Index

Group	Y	a	b	$\bar{R}^2$	$S_{y.x}$	Standard Error as % of Q_m & $Q_{m+\bar{s}}$ $-S_{y.x}$	$+S_{y.x}$
A	m	.376	1.164	.971	.095	-19.6	24.5
	m+$\bar{s}$	.680	1.137	.961	.108	-22.0	28.2
B	m	.255	1.134	.946	.137	-27.0	37.1
	m+$\bar{s}$	.375	1.172	.932	.160	-30.8	44.9
C	m	.644	1.135	.802	.184	-34.5	52.8
	m+$\bar{s}$	.852	1.149	.791	.192	-35.7	55.6
D	m	.701	.863	.858	.078	-16.4	19.7
	m+$\bar{s}$	1.188	.755	.810	.089	-18.5	22.7
All	m	.676	1.057	.907	.204	-37.5	60.0
	m+$\bar{s}$	1.000	1.024	.894	.213	-38.8	63.3
6 Stations	m	2.141	.693	.983	.015	-3.4	3.5
Main Stem	m+$\bar{s}$	2.230	.719	.943	.029	-6.5	6.9

General equation, $Y = a + bX$
where a is a regression constant,
and b is a regression coefficient,
and $X = \log DA \sqrt{S}$

therefore, to investigate means of resolving synthetic frequency curves into hurricane and nonhurricane components. Investigation and procedures for this purpose are described in the following paragraphs.

83. The annual peak flow frequency curve which is constructed without regard to the type of storm has been termed the "mixed" curve. The resolution of "mixed" curves into hurricane and nonhurricane components of 18 stations was discussed previously in paragraph 73. Resolution of the mixed curve for any stream in the Delaware basin may be accomplished with generalizations based on regression analyses of the observed frequency data of these 18 stations. The following generalized relations were obtained by regression of nonhurricane and hurricane flows on the mixed series flows at the indicated frequencies.

TABLE M-16
EQUATIONS FOR ESTIMATING HURRICANE AND NONHURRICANE COMPONENTS OF THE FREQUENCY CURVE

Frequency	Regression Equation	Coefficient of Determination	Standard Error of Estimate
	where, NH = nonhurricane flow H = hurricane flow M = mixed-series flow	$\bar{R}^2$	$S_{y.x}$
nonhurricane			
1%	Log NH = -.056 + .996 Log M	0.992	0.057
90%	Log NH = +.020 + .992 Log M	0.999	0.024
hurricane			
0.5%	Log H = +.171 + 1.018 Log M	0.978	0.098
1%	Log H = +.105 + 1.009 Log M	0.988	0.070
5%	Log H = -.087 + .985 Log M	0.998	0.031
10%	Log H = -.195 + .973 Log M	0.991	0.061

84. Graphic solution of these equations may be performed with the curves of plate 37. Although equations are shown for four hurricane flow frequencies (0.5, 1, 5 and 10%), computation of only the 0.5% and 10% flows is needed to define the hurricane component adequately. The foregoing equations were applied to synthesis of hurricane and nonhurricane curves from the observed "mixed" series adjusted for length of record. The reconstituted components are compared with the observed curves on plates 38 through 40.

85. Composite Annual Frequency Curves. The previous discussion has been concerned with derivation of frequency curves and their resolution into hurricane and nonhurricane components. It is of interest

now to consider the interpretation of these curves with respect to their application in the estimation of average annual damages. If sufficient flood damage data were available so that they could be classified as to the type of storm which caused the flood, then the damage curves could also be divided into two components, damages caused by hurricane floods and damages by nonhurricane floods. It is recognized that in some instances and localities these two types of damage may vary greatly. However, flood damage data in the Delaware River basin are not detailed sufficiently to make a damage analysis according to storm type. Therefore, in order to assign appropriate weight to hurricane and nonhurricane floods, it was necessary to recombine the two component parts into a single composite annual frequency curve for application to all flood damages. Since hurricane and nonhurricane storms are not mutually exclusive, combination of the component probabilities must be accomplished in a manner which permits assignment of the annual flood origin either to a hurricane or to a nonhurricane type event but which precludes assignment to both flood causes in any one year. This condition is satisfied by correcting the sum of the hurricane and nonhurricane probabilities by a term which represents the probability of simultaneous occurrence of both as the flood peak source for any one year. The correction is made by deduction of the product of these probabilities. Thus the composite probability may be expressed as:

$$P_C = P_H + P_{NH} - (P_H)(P_{NH}),$$

where P_C is the composite annual frequency for any flood without restriction as to storm cause, P_H is the hurricane frequency and P_{NH} is the nonhurricane frequency. This method of combining the hurricane and the nonhurricane populations produces a composite frequency curve which closely follows the hurricane population at high flows and approaches the nonhurricane population curve at middle and low flows.

86. The graphic representation of these relations is shown in figure 1 on plate 41. Curve A is the "mixed" Beard curve obtained from computation of mean and standard deviations of the annual series without regard to storm causes. Ninety percent confidence limits on curve A are shown by the five and ninety-five percent error limit curves. Curves B and C are the hurricane and nonhurricane Beard curves obtained by stratification of the data and estimation of the appropriate statistics for each population separately. Curve D is the composite of the hurricane and nonhurricane populations combined in the manner described in the preceding paragraph.

87. In order to use a frequency curve in economic studies it is necessary, in most cases, to develop a partial duration curve which considers more than one flood a year. Langbein 8/ developed a method

8/ Langbein, W. B., Annual Floods and the Partial-Duration Flood Series, Transactions American Geophysical Union, December 1949, Volume 30, Number 6, pages 879-881.

of constructing a partial duration curve from the annual series. Application of his method to annual peak frequency curves for stations in the Delaware River basin indicates a slightly different relationship between these two series. Whereas the exponential factor of the partial duration probabilities was -1 in Langbein's relation, it is found to be -1.15 for streams in this basin. Thus $P_a = e^{-1.15\ P_p}$, where P_a is the complement of the annual exceedence frequency, and P_p is the partial duration series frequency for the same peak discharge. The difference in exponents is due partly to differences in topography, geology and climate, and partly to the use of different plotting positions (Langbein: $P_p = m/N$; Beard $P_p = (2m-1)/(2N)$). Using P_c for the composite annual frequency, $P_a = (1-P_c)$ and solving for P_p,

$$P_p = \frac{\log_e (1-P_c)}{-1.15}$$ which is the relation used for determining the

values given in column 2 of table M-17. These values were used for the construction of curve E from curve D in figure 2 on plate 41.

TABLE M-17
PARTIAL DURATION EQUIVALENT OF ANNUAL SERIES

Annual Exceedence Frequency	Partial Duration Series Frequency
.30	.309
.40	.443
.50	.604
.60	.800
.684	.999*
.70	1.05
.80	1.40
.90	2.00
.95	2.61
.99	4.00

*Limit of probability paper (Code #3128)

88. PRESENTATION OF FINAL RESULTS OF FREQUENCY STUDY. The foregoing procedures provide an objective means of constructing frequency curves for any ungaged streams in the Delaware River basin. A synthetic frequency curve of mixed storm occurrences can be derived from generalized curves based on physical basic characteristics which may be readily measured on topographic maps. The frequency curve of mixed storm occurrences can be broken down into hurricane and nonhurricane

populations from generalized curves. These populations can be recombined according to the laws of probability to develop a composite annual curve and then expanded by the partial duration formula determined for the Delaware River basin into a partial duration frequency curve for all flows. A detailed discussion of the sequential procedures has been presented for the main purpose of demonstrating the rationale of the method and documenting the development of the procedure. For computation purposes, however, the final results are presented in graphic form on plates 44 through 48. The families of curves presented on these plates permit direct synthesis of the final composite partial duration frequency curve. The curves are entered with DA $\sqrt{S_{s+}}$ and flows at 0.1, 0.2, 0.5, 1.0, 2.0, 5.0, 10.0, 20, 50, 90, 100, 200 and 400 percent frequency are read directly from the vertical scale. The curves so obtained, then, represent estimated natural frequencies for streams in the Delaware River basin.

89. COMPARISON OF FLOOD FREQUENCIES WITH THOSE BASED ON OTHER METHODS OF ANALYSES. A variety of methods has been proposed for determining flood frequencies, but none is completely satisfactory for establishing reliable frequencies for the rare occurrences. Plotting point methods tend to assign too much weight to the occurrence of a rare flood in a short period and are largely dependent on the length of record. Statistical analyses such as Beard's tend to rely heavily on the bulk of mid-range floods in the estimation of population parameters and have the undesirable effect of assigning unreasonably low chance of occurrence to the rarer floods. Investigators have devised schemes for counteracting the disadvantages of the various methods and expert opinion is divided as to which of these schemes is the best. One such scheme is the adoption of a special kind of graph paper based on Gumbel's theory of extreme values, which purports, by a prearranged distortion of the probability scale, to distribute the extremes more closely to positions they might be expected to occupy in a more complete frequency array. This method if commonly used by the U. S. Geological Survey. Another scheme is the stratification of the data into different populations according to associative flood causes and the application of statistical analysis to the individual samples so obtained. This latter scheme puts the rarer occurrences into groups where they are less influenced by a preponderance of more common flood occurrences and thereby reassigns more realistic frequencies to them. Both schemes have merit and it is debatable whether the results of one are superior to those of the other. In this study preference was given to the statistical approach with stratification because of the rational processes involved and because of its general applicability to the amplification of studies currently being undertaken in Corps offices throughout the country, all of which studies are based on Beard's method. For illustrative purposes, however, a comparison was made with the U.S.G.S. method on plates 42 and 43 for several selected

stations in the Delaware River basin. It appears from these comparisons that results of either method are not too widely divergent.

90. MODIFICATION OF FLOOD FREQUENCY CURVES. The flood frequency curve and its modification by flood control projects constitutes a basic tool for derivation of flood control benefits attributable to specific projects. The usual procedure is to determine the effects of a project or group of projects at downstream damage reaches by adjustment of the frequency curve so as to reflect the reduction of peak flows due to the operation of the projects. In the present study these adjustments were made by holding the natural frequency of a particular flood constant and plotting the reduced peak discharges at the same frequency. The effects of the proposed reservoir projects on four major floods of record and a hypothetical basin project flood were determined and plotted as reduced peak flows below the natural frequency curve. A modified frequency curve was drawn through the five plotted points using the shape of the natural curve as a general guide.

91. Effect of Existing Reservoirs and Projects under Construction. In order to evaluate properly the net benefits attributed to individual projects, the natural frequency curves were first modified for the effects of existing reservoirs and those reservoir projects now under construction. The existing reservoirs and projects under construction consist of New York City's water supply reservoirs at Cannonsville, Downsville, and Neversink; the Corps of Engineers' flood control reservoirs at Prompton, Dyberry, and Bear Creek; and the Pennsylvania Power and Light Company project on Wallenpaupack Creek. In addition, frequency curves for Lehigh River were modified for the effect of the local flood protection projects for the Allentown - Bethlehem area which are now under construction by the Corps of Engineers. Downstream effects of Cannonsville, Pepacton, Neversink, and Wallenpaupack were determined with pool levels at spillway crest elevation since no storage is reserved for flood control at these projects. Other existing projects in the basin such as the Rockland Light and Power development on the Mongaup River, and minor water supply projects were not taken into account because of the small amount of storage involved. The natural frequency curve for Delaware River at Trenton and the modifications by existing projects and those under construction are shown on plate 49.

92. FREQUENCY OF LOW FLOWS. The most damaging effect of low flows on agricultural and industrial operations, and on municipal and domestic water needs results from the prolonged duration of subnormal flows rather than the lowest instantaneous discharge during a given time period. Therefore, the low flow frequency analysis in the Delaware River basin was treated as a volume-duration problem and studies were made on 24 streams throughout the basin for low flow volumes with durations of 7, 15, 30, 60, 120 and 183 days. Since runoff volumes do

not follow a normal distribution even with logarithmic transformation of the data, the asymmetry of the frequency distribution (skewness) was adjusted for by the adoption of Pearson Type III distribution. The skew coefficient was used in conjunction with the mean and standard deviation to compute seven points on the frequency curve from 0.1 percent to 99.9 percent. These curves are shown on plate 50 for selected stations in the basin.

93. UNIT HYDROGRAPHS. Unit hydrographs were required for gaged and ungaged subareas of the Delaware River basin for purposes of deriving synthetic flood hydrographs of runoff from transposed and hypothetical storms. Unit hydrographs for 82 subareas were derived from observed floods at existing stream gaging stations in the basin. For the remaining subareas, unit hydrographs needed in planning studies were developed synthetically from generalized studies utilizing empirical relations of unit hydrograph features versus basin characteristics. The derivation of unit hydrographs for gaged areas will be described subsequently. It consists of analysis of existing data with regard to the determination of time and areal distribution of precipitation, the determination of losses and rainfall excess, and the separation of the hydrographs into components of net surface flow and base flow. The development of an S-curve technique for construction of synthetic unit hydrographs for ungaged areas is discussed in detail in paragraph 104.

94. Basic Data and Studies for Derivation of Unit Hydrographs for Gaged Areas. Data were obtained from U. S. Geological Survey records of stage and streamflow, U. S. Weather Bureau precipitation records, and Corps of Engineers storm studies for the development of unit hydrographs at existing stream gaging stations. For most stations the flood periods of May 1942, December 1952, and August 1955 were used for unit hydrograph analyses. Where sufficient basic data on flow or precipitation were not available for these floods, other flood periods that met the criteria outlined below were utilized. Detailed studies of streamflow records indicated that runoff from several of the gaged subareas is affected by upstream regulation. Therefore, unit hydrographs were not derived at these locations but were developed synthetically from generalized studies, except where it was possible to correct for the effect of storage as in the case of Fishs Eddy, in August 1955, regulated by Pepacton Reservoir.

95. Choice of floods for unit hydrograph studies was dictated primarily by the availability of hourly precipitation data or storm studies from which time and areal distributions of precipitation could be obtained. In general, criteria used for selection of storm-flood periods were:

a. that the hydrograph of flood runoff be a well isolated event, fairly free from effects of antecedent or subsequent precipitation;

b. that the volume of flood runoff be in excess of one inch;

c. that the hydrograph be well defined and single peaked; and

d. that continuous stage records be available for the period under investigation.

96. Storm rainfall amounts were obtained from hourly records of precipitation published in Weather Bureau Climatological Bulletins, or from part I of storm studies. Storm totals of rainfall for both recording and nonrecording stations were plotted on a map and isohyets were drawn. Isohyetal maps in storm studies and special Weather Bureau or USGS reports were used where available. Basin average storm totals were computed from the isohyetal maps by planimetering. Time distributions of the storm totals were based on distributions at recording stations. Generally, averages of several different combinations of stations were computed to find a distribution that appeared reasonably oriented to the discharge hydrograph with respect to the time of separation of peak rainfall and peak discharges; the coincidence of times of initial hydrograph rise and major rise in storm intensity; the duration of rainfall excess with respect to time of peak; and the shape of rainfall distribution histogram with respect to the shape of the hydrograph.

97. Several basic assumptions were used in the determination of rainfall excess, loss, and infiltration rates. The volume of rainfall excess was taken as the volume of the net flow in units of inches depth on the drainage area. The time of beginning of rainfall excess was assumed to be coincident with the beginning of the net flow hydrograph. The distribution of rainfall excess was based on an assumed distribution of loss over the period of rainfall excess duration. Loss was computed as the difference between the runoff and the total storm rainfall. The initial loss is that portion of the storm rainfall occurring prior to the beginning of rainfall excess. The infiltration loss is defined as that portion of the loss occurring during the period of rainfall excess. The estimation of infiltration loss distribution was somewhat objective, the larger infiltration rates being assigned to the first one or two increments of time during the rainfall excess period with rapid reduction to a uniform value for the remainder of the period. The final loss is that portion of the loss occurring after the end of rainfall excess. In general, rainfall rates during the period of final loss were below the lowest infiltration rate for the storm.

98. Hydrograph Analysis. The observed hydrograph in three-hourly detail was separated into components of surface flow and base flow. The base flow curve was drawn as a straight line starting at the time which would make the base length of the resulting unit

hydrograph compatible with a preassigned flow duration. The preassigned flow duration was based in part on the duration of the synthetic unit hydrograph and in part on a knowledge of the general hydraulic behavior of the area in question as exhibited by unit hydrographs for nearby streams. (See plate 51). The base flow increase was limited to between 2 and 10 cubic feet per second per square mile (c.s.m.). In some instances, where early precipitation produced an initial rise, the base flow curve was started at the lower earlier flow and a suitable recession was drawn to isolate and remove the effect of the undesirable initial rise. Three-hourly ordinates of the net flow hydrograph were obtained by subtracting the base flow from the observed flows. The volume of net flow (direct storm runoff, or surface flow) was computed by summation of the ordinates of the net flow hydrograph and converted to inches of depth on the drainage area.

99. The S-Hydrograph. A technique for deriving unit hydrographs of a specific duration from floods caused by storms of different durations with nonuniform rainfall rates was described in 1939 by Morgan and Hullinghorst 9/ in an unpublished paper entitled "Unit Hydrographs for Gaged and Ungaged Watersheds." There follows a discussion of the application of their technique to the derivation of three-hour unit hydrographs for streams in the Delaware basin. The S-hydrograph was constructed by summation of flows of a set of identical hydrographs obtained by repeating the net flow hydrograph at time intervals equal to the duration of the rainfall excess (generation period). The summation process was carried on until equilibrium flow was attained. The S-hydrograph exhibited an irregularity or waviness associated with nonuniformity of the rainfall excess pattern. The irregularity was eliminated by drawing a smooth curve through the waves of the S-hydrograph so as to balance areas by inspection and so as to reach a maximum value (average equilibrium flow) at the time of equilibrium. The time at which equilibrium flow was reached was defined by taking the difference between total duration of net flow discharge and the runoff generation period. Three-hourly ordinates of the smoothed S-hydrograph were divided by the maximum value of the ordinate to obtain an S-curve. The "S-curve" is then distinguished from the S-hydrograph by its dimensionless vertical scale. The vertical scale of the curve so obtained represents the cumulative percentage of unit runoff. Differences between successive 3-hourly values of the S-curve were computed to obtain the 3-hour unit hydrograph. (The unit hydrograph, thus derived, generally required some graphic smoothing, particularly of the recession portion, for shape and continuity). The ordinates of the unit hydrograph were multiplied by the basin c.f.s. - equivalent of one inch per 3 hours for application to the 3-hour rainfall excess rates in inches. See figure 1, plate 51, for a sample reconstitution of the flood hydrograph.

9/ Morgan, R. and Hullinghorst, D. W. - Unit Hydrographs for Gaged and Ungaged Watersheds, Corps of Engineers, Binghamton, N. Y., 1939.

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100. Adopted Unit Hydrographs. It was found that unit hydrographs independently derived from several floods on an area agreed closely with regard to general shape, and magnitude and timing of the peak. The average unit hydrograph was determined by aligning the peaks in time and drawing an average by inspection. Average unit hydrographs so obtained were adopted as final. These are presented for 82 streams in table M-18. Appropriate forms prescribed by Office of Chief of Engineers for unit hydrograph compilations, Civil Works Investigations Project CW 153, were completed and submitted to higher authority.

101. GENERALIZED UNIT HYDROGRAPHS FOR AREAS LACKING STREAMFLOW RECORDS. The need for unit hydrographs for areas having insufficient or no streamflow records has led to the development and publication of a variety of methods for constructing synthetic unit hydrographs. Among these, the more widely used are the methods of Snyder 10/ and Taylor. 11/ These methods were investigated and found reasonably adequate when empirical constants related to Delaware basin streams were developed for them. Independent exploration of the possibility of deriving synthetic unit hydrographs by relation of the S-curve to basic characteristics was undertaken resulting in the formulation and adoption of a simpler, more objective method equivalent in accuracy to that of widely used methods of greater complexity.

102. Terminology and Basic Data. Unit hydrographs and S-curves for the 82 gaging stations discussed in paragraphs 93 to 100, inclusive, will be designated hereafter as derived unit hydrographs and derived S-curves to distinguish them from the synthetic unit hydrographs and synthetic S-curves developed for ungaged areas. Topographic characteristics of drainage basins and a set of derived unit hydrographs constituted the basic data of this study. Stream length and slope, stream length to the center of gravity of the area, and drainage area were readily measured from USGS quadrangle sheets (1:62,500). The symbols for and description of these are:

Stream length, L. The length of the longest watercourse measured in miles. (Range: 2.10 - 93.2 mi.).

Stream slope, S_{st}. The square of the harmonic mean of the square roots of slopes of equal segments of stream length. The average stream slope computed in this way is equivalent to the slope of a

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10/ Snyder, F.F. - Synthetic Unit Graphs - Transactions, Amer. Geophysical Union, pt. 1, pp 447-454, 1938.
11/ Taylor, Arnold B. and Schwarz, Harry - Unit Hydrograph Lag and Peak Flow Related to Basic Characteristics - Transactions, Amer. Geophysical Union, April 52.

TABLE M-18

3-HOUR UNIT HYDROGRAPHS - DELAWARE RIVER BASIN

	E.Br.Del. Riv. at Margaret-ville	Platte Kill at Dunraven	Mill Br. at Arena	Tremper Kill nr. Shavertown	Terry Clove Kill nr. Pepacton	Coles Kill nr. Pepacton	E. Br. Del. River at Downs-ville	E. Br. Del. Riv. at Harvard	Beaver Kill nr. Turnwood	Beaver Kill nr. Craigie Clair	Willowemoc Cr. nr. Livingston Manor	L.Beaver Kill nr. Living-ston Manor	Beaver Kill at Cooks Falls	E.Br.Del. Riv. at Fishs Eddy	W.Br.Del Riv. at Delhi
D.A. (Sq.Mi.)	163.0	34.7	25.0	33.0	14.1	28.0	373.0	443.0	40.8	82.0	63.0	19.8	241.0	783.0	142.0
L (Miles)	19.5	9.56	9.32	8.78	5.08	7.00	42.4	55.2	13.3	23.4	19.0	7.80	32.6	62.6	25.0
L_{ca} (Miles)	7.55	5.53	4.60	5.27	2.68	4.25	22.4	31.1	6.35	9.71	10.0	3.50	16.0	38.6	13.0
S_{st} (ft./ft.)	0.0024	0.0128	0.0245	0.0142	0.0169	0.0156	0.0019	0.0018	0.0149	0.0108	0.0075	0.0128	0.0073	0.0017	0.0037
Q_p (cfs)	7,600.	2,400.	1,800.	1,900.	1,100.	1,670	9,000	11,000	2,900	4,700	3,330	1,360	13,000	21,060	4,950
q_p (cfs/sq.mi.)	46.5	69.3	72.0	57.6	78.0	59.8	24.1	24.8	71.1	57.3	52.3	68.8	53.9	26.9	34.8
t_p (Hours)	5.5	3.0	3.0	3.5	2.0	3.5	13.0	14.5	3.5	6.0	5.2	3.5	6.5	7.0	8.0
W_{50} (Hours)	9.0	4.2	5.0	7.0	5.4	5.5	22.5	20.0	6.8	7.0	8.8	7.0	7.0	16.4	13.0
W_{75} (Hours)	4.5	3.0	2.9	4.0	3.1	2.9	10.9	12.0	4.0	4.0	4.8	4.3	3.7	8.2	6.5
Base L. (Hours)	60.0	42.0	39.0	45.0	30.0	51.0	72.0	87.0	39.0	51.0	48.0	30.0	60.0	93.0	66.0
t_r (Hours)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
(Hours)								**Discharge (C.F.S.)**							
0	0	0	0	0	0	C	0	0	0	0	0	0	0	0	0
3	1,230	1,600	1,400	890	1,060	1,080	1,900	1,430	1,320	460	950	850	2,640	5,050	2,130
6	5,790	1,600	1,200	1,780	780	1,260	4,010	4,070	2,460	3,900	3,200	1,280	9,490	17,700	4,270
9	7,030	910	740	1,200	430	750	6,180	6,660	1,410	4,240	2,820	720	11,610	21,060	4,830
12	4,750	720	530	720	280	550	8,180	9,320	1,010	2,400	1,800	500	6,530	18,700	3,700
15	3,500	600	410	520	200	440	8,990	10,940	750	1,600	1,180	350	4,610	15,000	2,930
18	2,740	500	330	440	130	370	7,780	10,760	560	1,220	900	260	3,370	12,300	2,350
21	2,100	410	250	380	80	310	6,740	9,170	420	940	700	170	2,900	10,110	1,890
24	1,720	350	200	320	50	270	5,780	7,470	310	740	540	100	2,300	8,750	1,560
27	1,400	270	150	270	20	190	4,970	5,770	230	560	420	30	1,830	7,600	1,280
30	1,120	210	100	220	0	160	4,410	4,620	160	460	330	0	1,480	6,230	1,100
33	910	150	60	160		130	3,850	3,820	100	380	250		1,190	5,730	980
36	740	100	10	110		100	3,290	3,200	50	270	200		980	5,220	790
39	600	50	0	60		80	2,810	2,660	0	220	130		830	4,710	640
42	460	0		20		50	2,490	2,330		140	90		670	4,040	550
45	320			0		40	2,000	2,060		70	50		520	3,710	460
48	280					20	1,680	1,810		40	0		360	3,200	370
51	180					0	1,440	1,600		0			260	2,860	240
54	120						1,120	1,400					160	2,700	180
57	70						880	1,250					100	2,350	120
60	0						720	1,100					0	2,180	90
63							560	930						1,850	60
66							320	810						1,680	0
69							100	660						1,510	
72							0	520						1,170	
75								380						1,010	
78								280						840	
81								150						510	
84								100						330	
87								0						210	
90														130	
93														0	
96															
99															
102															
105															
Total	35,060	7,470	5,380	7,090	3,030	5,800	80,200	95,270	8,780	17,640	13,560	4,260	51,830	168,440	30,520

TABLE M-18 (Contd)

3-HOUR UNIT HYDROGRAPHS - DELAWARE RIVER BASIN

		L.Del. Riv. nr. Delhi	W.Br. Del. R. at Wal-ton	Trout Cr. at Cannons-ville	Cold Spring Br. at China	Oquaga Cr. at Deposit	W.Br.Del. Riv. at Stiles-ville	W.Br.Del. Riv. at Hale Eddy	Callicoon Cr. at Callicoon	Tenmile Riv. at Tusten	Lackawaxen Riv. at Prompton	Dyberry Cr. at Dyberry	Lacka-waxen R. nr. Hones-dale	Middle Cr. nr. Hawley	Lacka-waxen Riv. at Hawley	Mongaup Riv. nr. Mongaup
D.A.	(Sq.Mi.)	49.8	331.0	49.5	1.51	66.0	456.0	593.0	111.0	45.0	59.7	63.2	164.0	78.4	290.0	202.0
L	(Miles)	14.4	42.9	13.1	2.10	15.0	68.0	76.5	19.4	12.5	20.0	14.1	23.6	19.3	33.3	33.0
L_{ca}	(Miles)	8.50	20.2	8.40	0.74	8.62	39.9	34.5	11.1	6.80	8.5	6.50	7.50	9.55	17.5	16.9
S_{st}	(ft./ft.)	0.0096	0.0027	0.0067	0.0540	0.0078	0.0023	0.0020	0.0066	0.0030	0.0081	0.0096	0.0103	0.0053	0.0043	0.0053
Q_p	(cfs)	2,520	9,600	2,790	138.	2,660	9,710	11,500	5,180	2,200	3,500	3,500	7,100	3,400	13,800	6,770
q_p	(cfs/sq.mi.)	50.5	29.0	56.4	91.3	40.3	21.3	19.4	46.7	48.9	58.6	55.4	43.2	43.3	47.6	33.5
t_p	(Hours)	4.5	12.0	5.5	2.0	7.5	13.0	18.0	5.5	6.0	5.7	6.0	5.5	6.0	8.5	8.5
W_{50}	(Hours)	7.8	19.0	7.5	4.5	11.8	24.5	26.7	9.4	10.2	9.0	9.0	12.0	11.0	11.0	18.0
W_{75}	(Hours)	3.3	11.0	4.0	2.2	7.2	14.0	16.5	4.6	5.6	4.8	4.5	6.0	5.6	5.8	10.9
Base L.	(Hours)	51.0	66.0	48.0	27.0	48.0	87.0	105.0	51.0	48.0	36.0	42.0	51.0	48.0	45.0	54.0
t_r	(Hours)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
(Hours)		Discharge (C.F.S.)														
0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3		730	900	640	115	720	2,060	640	1,980	300	800	700	2,510	600	1,900	390
6		2,520	3,600	2,500	81	1,960	4,710	3,440	5,060	1,500	2,800	2,800	6,640	2,950	5,800	5,260
9		1,640	6,500	2,180	47	2,660	7,360	6,120	4,350	2,100	3,100	3,100	6,240	3,350	13,000	6,730
12		1,230	9,100	1,330	32	2,300	9,520	8,930	3,100	1,600	2,100	2,100	4,940	2,550	12,500	6,360
15		940	9,400	940	22	1,550	9,710	10,970	2,220	1,150	1,300	1,200	3,770	1,900	9,800	5,870
18		760	8,200	710	15	1,080	9,320	11,480	1,670	810	900	900	2,820	1,430	6,400	5,040
21		620	6,900	560	9	870	8,040	11,480	1,310	580	700	700	2,150	1,100	4,300	4,130
24		530	5,500	450	4	720	6,870	10,720	1,050	440	500	600	1,620	850	3,000	3,210
27		430	4,200	360	0	610	5,890	9,440	840	350	300	500	1,310	660	2,200	2,170
30		350	3,200	300		510	5,100	7,910	690	270	200	400	1,020	510	1,600	1,390
33		290	2,600	230		410	4,410	6,510	550	210	100	300	780	390	1,200	910
36		240	2,100	170		330	3,730	5,490	410	160	0	200	600	280	800	650
39		180	1,800	130		240	3,240	4,590	310	110		100	420	190	500	430
42		130	1,600	90		160	2,740	3,960	190	70		0	280	100	200	300
45		90	1,400	50		80	2,450	3,440	100	30			140	40	0	220
48		40	1,200	0		0	2,060	2,930	50	0			40	0		130
51		0	1,000				1,860	2,680	0				0			40
54			800				1,670	2,300								0
57			600				1,470	2,040								
60			400				1,280	1,790								
63			200				1,080	1,660								
66			0				880	1,400								
69							690	1,280								
72							590	1,150								
75							490	1,020								
78							390	900								
81							290	770								
84							200	650								
87							0	560								
90								470								
93								360								
96								270								
99								170								
102								80								
105								0								
Total		10,720	71,200	10,640	325	14,200	98,100	127,600	23,880	9.680	12,800	13,600	35,280	16,900	62,400	43,430

TABLE M-18 (Contd)

3-HOUR UNIT HYDROGRAPHS - DELAWARE RIVER BASIN

	Neversink Riv. at Claryville	Neversink R. at Neversink	Neversink R. at Woodbourne	Neversink Riv. at Oakland Valley	Neversink Riv. at Godeffroy	Bush Kill at Shoemakers	Flatbrook nr. Flatbrookville	Brodhead Cr. at Minisink Hills	Paulins Kill at Blairstown	Pequest Riv. at Huntsville	Pequest Riv. at Pequest	Beaver Br. nr. Belvidere	Lehigh Riv. at Stoddartsville	Lehigh Riv. at Tannery	Dilldown Cr. nr. Long Pond
D.A. (Sq.Mi.)	65.6	93.0	113.0	222.0	302.0	117.0	65.1	259.0	126.0	31.4	108.0	36.2	91.7	322.0	2.39
L (Miles)	13.7	23.5	28.3	51.5	57.1	23.4	23.7	25.2	26.5	6.25	24.9	13.0	16.6	32.4	2.40
L_{ca} (Miles)	9.75	15.3	16.7	31.0	22.5	18.4	12.4	14.3	13.6	3.50	10.2	7.70	9.0	18.0	1.20
S_{st} (ft./ft.)	0.0164	0.0106	0.0081	0.0051	0.0056	0.0071	0.0033	0.0080	0.0022	0.0019	0.0011	0.0038	0.0047	0.0046	0.0188
Q_p (cfs)	4,100	5,000	6,150	9,550	9,800	2,520	2,380	12,200	3,040.	630.	2,200	1,000	3,500	12,400	187.
q_p (cfs/sq.mi.)	62.4	53.8	54.4	43.0	32.4	21.5	36.6	47.1	24.1	20.1	17.5	27.6	38.2	38.5	78.2
t_p (Hours)	4.5	5.0	6.0	7.0	10.5	10.5	13.5	6.3	16.5	22.5	13.0	15.0	9.5	10.5	2.5
W_{50} (Hours)	7.2	9.8	7.3	12.0	15.0	26.7	14.2	7.8	23.2	31.0	27.5	20.1	11.2	13.2	6.3
W_{75} (Hours)	4.1	5.3	3.7	7.0	8.8	13.8	8.1	4.9	12.3	18.5	15.5	11.4	6.0	7.0	2.9
Base L. (Hours)	33.0	54.0	63.0	51.0	69.0	72.0	57.0	66.0	66.0	66.0	81.0	60.0	63.0	56.0	27.0
t_r (Hours)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
								Discharge (C.F.S.)							
(Hours)															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	2,000	2,000	1,410	1,530	600	630	160	1,900	230	30	220	40	390	1,300	120
6	4,100	4,960	4,910	8,120	4,000	1,430	550	7,200	700	90	740	80	1,180	3,000	157
9	2,700	4,280	5,110	9,500	7,700	2,290	1,210	11,200	1,350	180	1,380	150	2,860	6,100	90
12	1,800	2,880	3,210	7,690	9,800	2,520	1,920	7,400	2,100	320	1,900	530	3,400	12,400	59
15	1,300	1,840	2,040	5,880	9,000	2,370	2,380	5,300	2,750	450	2,150	980	2,660	10,800	38
18	900	1,160	1,480	4,060	7,000	2,140	2,020	3,700	3,040	550	2,170	960	1,830	8,800	26
21	600	760	1,170	3,040	5,200	1,910	1,540	3,100	2,820	610	2,020	880	1,380	7,100	16
24	400	560	920	2,200	4,000	1,710	1,050	2,600	2,340	630	1,790	760	1,200	5,500	8
27	200	420	750	1,720	3,200	1,540	730	2,200	2,000	620	1,580	660	910	4,200	0
30	100	320	630	1,340	2,600	1,360	580	1,900	1,740	570	1,380	570	830	3,100	
33	0	260	560	1,000	2,200	1,210	460	1,700	1,500	510	1,210	470	670	2,300	
36		200	460	670	1,900	1,080	380	1,500	1,310	450	1,070	400	510	1,700	
39		140	390	480	1,600	960	310	1,300	1,130	400	950	340	450	1,200	
42		100	340	290	1,400	830	250	1,100	980	350	850	280	370	900	
45		60	270	190	1,200	700	190	900	850	280	750	230	320	500	
48		40	240	50	1,000	630	130	800	680	230	660	180	280	300	
51		20	190	0	800	530	80	600	550	180	560	140	180	100	
54		0	120		600	430	50	500	420	140	480	90	120	0	
57			70		500	350	0	400	310	90	400	50	100		
60			50		400	250		300	210	50	320	0	80		
63			0		200	180		100	100	20	240		0		
66					100	100		0	0	0	190				
69					0	20					120				
72						0					50				
75											30				
78											20				
81											0				
84															
87															
90															
93															
96															
99															
102															
105															
Total	14,100	20,000	24,320	47,760	65,000	25,170	13,990	55,700	27,110	6,750	23,230	7,790	19,720	69,300	314

TABLE M-18 (Contd)

3-HOUR UNIT HYDROGRAPHS - DELAWARE RIVER BASIN

		Wild Cr. at Hatchery	Pohopoco cr. nr. Parryville	Aquashicola Cr. at Palmerton	Lehigh Riv. at Walnutport	L.Lehigh Riv nr. Allentown	Jordan Cr. at Allentown	Monocacy Cr. at Bethlehem	Lehigh Riv. at Bethlehem	Saucon Cr. at Lanark	S.Br. Saucon Cr. at Friedensville	Saucon Cr. at Friedensville	Musconetcong Riv. nr. Hackettstown 1/	Musconetcong Riv. nr. Bloomsbury 1/	Tohickon Cr. nr. Pipersville
D.A.	(Sq.Mi.)	16.8	109.0	76.7	889.0	80.8	75.8	44.5	1,279.0	12.0	10.6	26.6	44.4	117.4	97.4
L	(Miles)	6.50	24.9	22.4	71.7	20.5	30.0	14.2	93.2	5.80	4.84	8.95	9.75	40.0	23.0
L_{ca}	(Miles)	3.0	11.7	9.87	30.4	14.8	19.4	9.79	37.3	2.90	2.50	3.70	5.45	20.5	10.8
S_{st}	(ft./ft.)	0.0247	0.0034	0.0036	0.0036	0.0024	0.0024	0.0037	0.0027	0.0082	0.0092	0.0061	0.0034	0.0033	0.0020
Q_p	(cfs)	1,110	2,625	2,260	19,600	3,300	1,140	1,780	30,300	1,000	1,000	1460	930.	2,750.	7,200
q_p	(cfs/sq.mi.)	66.1	24.1	29.5	22.0	40.8	41.4	40.0	23.8	83.4	94.3	54.9	21.0	23.4	73.9
t_p	(Hours)	4.0	7.5	10.5	13.5	6.0	12.5	10.5	17.0	3.0	2.7	5.5	17.0	7.0	3.7
W_{50}	(Hours)	7.6	22.5	17.6	24.0	11.0	12.3	12.8	22.0	4.5	5.6	10.0	29.1	29.6	6.6
W_{75}	(Hours)	3.9	11.0	8.0	13.0	5.6	6.7	5.8	11.4	3.0	3.7	5.8	17.7	8.5	4.1
Base L.	(Hours)	39.0	76.0	69.0	84.0	66.0	48.0	50.0	96.0	33.0	27.0	45.0	66.0	63.0	32.0
t_r	(Hours)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
(Hours)									Discharge (C.F.S.)						
0		0	0	0	0	0	0	0	0	0	0	0	0	0	0
3		440	940	330	5,000	800	320	110	1,400	500	720	340	100	1,000	4,200
6		1,100	2,180	810	9,900	3,000	820	430	4,700	800	900	1,320	300	2,500	6,900
9		700	2,600	1,450	15,400	3,060	1,500	1,050	10,500	460	350	1,290	520	2,750	3,800
12		420	2,330	2,260	19,100	2,170	2,620	1,780	17,900	280	130	940	730	2,400	2,300
15		290	2,080	1,970	19,600	1,710	3,080	1,400	24,800	200	80	630	890	1,800	1,400
18		220	1,830	1,610	18,400	1,350	2,290	1,060	30,300	150	50	420	930	1,600	1,000
21		160	1,630	1,340	15,600	1,070	1,660	860	29,000	100	30	270	920	1,600	700
24		120	1,450	1,150	13,500	870	1,190	690	25,000	50	20	180	850	1,800	400
27		80	1,280	970	11,600	720	880	560	21,500	30	0	120	760	1,800	200
30		50	1,120	810	10,000	600	660	470	18,300	10		80	660	1,600	100
33		30	960	690	8,400	490	500	370	15,300	0		60	570	1,400	0
36		10	840	600	7,200	410	360	280	12,900			40	500	1,150	
39		0	730	510	6,000	330	230	210	10,900			20	420	950	
42			630	450	5,100	250	140	150	9,100			10	350	800	
45			560	370	4,400	180	50	100	7,600			0	290	650	
48			490	330	3,800	130	0	50	6,400				240	500	
51			430	270	3,300	100		0	5,300				190	400	
54			360	220	2,900	60			4,500				140	300	
57			310	160	2,400	30			3,800				100	200	
60			240	110	2,200	20			3,300				60	100	
63			190	70	1,900	10			2,700				30	0	
66			140	30	1,600	0			2,300				0		
69			90	0	1,300				1,900						
72			50		1,000				1,500						
75			0		800				1,300						
78					500				1,000						
81					300				700						
84					0				500						
87									300						
90									200						
93									100						
96									0						
99															
102															
105															
Total		3,620	23,460	16,510	191,200	17,360	16,300	9,570	275,000	2,580	2,280	5,720	9,550	25,300	21,000

1/ Does not include area above Lake Hopatcong

TABLE M-18 (Contd)

3-HOUR UNIT HYDROGRAPHS - DELAWARE RIVER BASIN

	Assunpink Cr. at Trenton	Crosswicks Cr. at Extonville	Neshaminy Cr. nr. Langhorne	N.Br. Rancocas Cr. at Pemberton	Schuylkill R. at Pottsville	Schuylkill R. at Landingville	L.Schuylkill R. at Tamaqua	Schuylkill R. at Berne	Tulpehocken Cr. at Reading	Schuylkill R. at Pottstown	Perkiomen Cr. at Graterford	Schuylkill R. at Phila.	Mantua Cr. at Pitman	Ridley Cr. at Moylan	Chester Cr. nr. Chester
D.A. (Sq.Mi.)	89.4	83.6	210.0	111.0	53.4	133.0	42.9	355.0	211.0	1,147.0	279.0	1,893.0	6.75	31.9	61.1
L (Miles)	19.3	14.0	34.0	17.9	12.2	22.4	11.65	36.3	33.5	77.0	28.4	121.0	3.08	9.25	20.1
L_{ca} (Miles)	7.8	8.35	17.7	9.85	5.05	16.4	4.80	22.3	16.1	31.3	13.50	57.0	1.70	7.10	9.70
S_{st} (ft./ft.)	0.0011	0.0009	0.0029	0.0014	0.0043	0.0036	0.0132	0.0033	0.0015	0.0014	0.0026	0.0008	0.0066	0.0053	0.0047
Q_p (cfs)	3,710.	1,600	10,400	1,500	2,550	3,660	2,500	10,900	6,300	20,000	16,500	58,000	350.	2,210	5,180
q_p (cfs/sq.mi.)	41.5	19.1	49.5	13.5	47.8	27.5	57.3	30.7	29.9	17.4	59.1	30.6	51.8	69.4	84.8
t_p (Hours)	7.5	23.5	10.5	34.5	5.5	6.5	3.5	9.5	7.5	22.5	6.5	11.5	6.0	4.5	2.5
W_{50} (Hours)	11.0	32.4	10.6	48.3	9.3	21.0	7.5	17.6	16.5	34.5	9.0	17.2	10.0	7.8	5.6
W_{75} (Hours)	6.2	19.2	7.5	33.0	4.9	8.2	3.8	9.9	7.5	21.5	5.5	9.0	5.5	4.2	2.9
Base L. (Hours)	72.0	72.0	60.0	84.0	60.0	66.0	45.0	57.0	66.0	87.0	39.0	69.0	36.0	33.0	36.0
t_r (Hours)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
(Hours)								Discharge (C.F.S.)							
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1,080	230	90	190	520	850	1,320	2,000	1,400	3,000	3,200	5,000	160	480	4,620
6	2,600	450	680	360	2,160	2,920	2,200	6,100	4,400	6,400	12,100	15,000	320	2,210	3,640
9	3,710	670	9,040	550	2,250	3,580	1,400	10,000	6,300	10,700	16,100	36,000	310	1,660	2,010
12	3,100	900	10,400	740	1,700	3,000	1,030	10,700	5,700	14,300	11,300	57,200	210	1,060	1,180
15	1,980	1,130	9,040	930	1,210	2,570	810	9,300	4,800	17,100	6,300	53,600	140	580	640
18	1,360	1,330	5,870	1,080	870	2,290	650	8,000	3,900	19,000	3,900	46,000	100	380	390
21	1,080	1,490	3,160	1,220	630	2,060	510	6,500	3,200	19,800	2,600	38,400	80	250	260
24	830	1,600	2,030	1,340	480	1,860	400	5,200	2,700	19,900	1,800	31,400	60	150	200
27	690	1,580	1,360	1,410	380	1,660	300	4,300	2,400	19,500	1,200	24,800	40	70	90
30	580	1,480	900	1,460	300	1,460	230	3,600	2,000	18,200	800	20,000	20	20	70
33	460	1,330	680	1,480	240	1,290	170	3,000	1,700	16,100	500	16,400	10	0	30
36	380	1,170	540	1,500	200	1,090	120	2,400	1,500	14,100	200	13,600	0		0
39	310	1,010	410	1,480	160	940	60	1,900	1,200	12,100	0	11,300			
42	250	860	320	1,460	130	800	20	1,400	1,000	10,300		9,400			
45	210	720	230	1,380	90	660	0	1,000	900	8,700		7,800			
48	170	580	180	1,260	70	510		600	700	7,600		6,400			
51	130	450	130	1,150	50	400		300	600	6,200		5,100			
54	100	340	80	1,030	30	290		100	400	5,200		3,900			
57	80	270	40	910	10	200		0	300	4,400		2,800			
60	60	180	0	760	0	110			200	3,700		1,800			
63	40	120		640		60			100	3,000		900			
66	20	70		520		0			0	2,400		400			
69	10	20		400						1,800		0			
72	0	0		290						1,300					
75				190						900					
78				100						600					
81				50						300					
84				0						100					
87										0					
90															
93															
96															
99															
102															
105															
Total	19,230	17,980	45,180	23,880	11,480	28,600	9,220	76,400	45,400	246,700	60,000	407,200	1,450	6,860	13,130

TABLE M-18 (Contd)

3-HOUR UNIT HYDROGRAPHS - DELAWARE RIVER BASIN

		Christina Riv. at Coochs Bridge	Red Clay Cr. at Wooddale	Brandy-wine Cr. at Chadds Ford	Brandy-wine Cr. at Wil-mington	Shell-pot Cr. at Wil-mington	Salem Cr. at Woodstown	White Clay Cr. above Newark	Leipsic R. nr. Cheswold
D.A.	(Sq.Mi.)	20.5	47.0	287.0	314.0	7.46	14.6	66.7	9.2
L	(Miles)	11.0	15.8	38.1	43.7	5.30	6.25	15.3	4.28
L_{ca}	(Miles)	5.20	8.25	19.2	26.8	2.70	3.35	9.90	2.40
S_{st}	(ft./ft.)	0.0049	0.0034	0.0022	0.0017	0.0121	0.0027	0.0038	0.0019
Q_p	(cfs)	1,200	3,000	10,100	11,100	830.	740.	4,700	400.
q_p	(cfs/sq.mi.)	58.6	63.8	35.2	35.4	111.2	50.5	70.6	43.2
t_p	(Hours)	4.5	5.5	9.5	14.5	2.5	6.5	3.5	7.5
W_{50}	(Hours)	10.0	8.9	14.5	16.5	5.0	10.1	7.5	12.8
W_{75}	(Hours)	7.5	5.2	9.0	10.2	3.1	6.1	4.3	6.6
Base L.	(Hours)	33.0	36.0	60.0	51.0	21.0	39.0	30.0	39.0
t_r	(Hours)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
(Hours)								Discharge (C.F.S.)	
0		0	0	0	0	0	0	0	0
3		600	300	1,000	1,000	550	250	3,580	80
6		1,160	2,690	5,000	2,800	630	570	4,610	230
9		1,070	2,660	9,200	5,400	260	720	3,120	400
12		700	1,920	10,000	8,700	110	550	1,610	340
15		340	1,130	8,500	11,000	40	380	720	260
18		220	600	6,700	10,700	20	250	320	200
21		150	350	4,500	8,800	0	160	200	160
24		100	220	3,300	6,800		110	110	120
27		50	130	2,700	4,100		70	60	90
30		20	70	2,300	2,700		50	0	60
33		0	30	1,900	1,900		20		30
36			0	1,600	1,400		10		10
39				1,300	1,000		0		0
42				1,100	600				
45				900	400				
48				700	200				
51				500	0				
54				300					
57				200					
60				0					
63									
66									
69									
72									
75									
78									
81									
84									
87									
90									
93									
96									
99									
102									
105									
Total		4,410	10,100	61,700	67,500	1,610	3,140	14,330	1,980

DEFINITION OF TERMS:

D.A.	..	drainage area in square miles
L	..	length of longest watercourse in miles
L_{ca}	..	stream length in miles to center of gravity of area (See par. 102)
S_{st}	..	average stream slope, ft. per ft. (See par. 102)
Q_p	..	peak value of unit hydrograph in cfs
q_p	..	peak value of unit hydrograph in cfs per sq. mi.
t_p	..	lag in hours from the time of the center of mass of rainfall excess to the time of the unit hydrograph peak
W_{50}	..	width in hours of the unit hydrograph at 50% of peak discharge
W_{75}	..	width in hours of the unit hydrograph at 75% of peak discharge
Base L	..	time in hours from beginning to end of unit hydrograph
t_r	..	unit rainfall duration in hours

uniform channel having the same length and travel time as the stream under investigation.11/ (Range: 5.82 - 285 ft./mi.).

Stream length to center of gravity, L_{ca}. Measured in miles along the main channel to a point closest to the center of gravity of the area.

Drainage area, DA. Values of drainage area published by the USGS were used where available, and were measured by polar planimeter on 1:62,500 quadrangle sheets for ungaged basins. (Range: 151 - 1,279 sq. mi.).

103. Characteristics of Derived Unit Hydrographs. The time and the magnitude of unit hydrograph peaks, and the time lags to 20, 40, 50, 60, 80 and 100 percent of unit hydrograph runoff were used as the basic derived unit hydrograph data for relation to basin characteristics. The time and the magnitude of peak are listed with unit hydrograph tabulations in table M-18. Percentage mass curves of unit hydrograph runoff were computed from derived average unit hydrographs for computation of time lags for various percentages of runoff. Fifty derived unit hydrographs were selected for establishing the final generalized relations on the basis of general similarity in drainage pattern.

104. Method for Defining Synthetic Unit Hydrographs. The methods of Snyder and Taylor-Schwarz present bases for estimating the magnitude and time of unit hydrograph peak for ungaged areas. The actual shaping of the unit hydrograph in these methods is based on widths at 50 percent and 75 percent of the peak and on a relation of the base length to time of peak. The independent method developed herein defines the entire shape in terms of time lags to preassigned percentages of the unit hydrograph runoff volume. Basin lag or time to 50 percent of unit runoff has been widely studied and related to basin topographic features. Clark 12/ related lag to a joint function of stream length and stream slope $(L/\sqrt{S_{st}})$ and Linsley 13/ included drainage area in the index $(L\sqrt{DA/S_{st}})$. Derivation of independent exponents by regression on the logarithms of the variables showed Linsley's index to be applicable only for estimating basin lag (time to 50 percent runoff). For lag times to percentages of runoff other than 50 percent, the exponents of L, S, and DA exhibited differing magnitudes and varying levels of significance. In general, however, it was found that drainage area had little effect on the relationship and that $(L/\sqrt{S_{st}})$ could be used as a universal index for this basin.

12/ Clark, C. O. - Storage and the Unit Hydrograph - ASCE Transactions, Vol. 110, 1945, pp. 1419-1488.
13/ Linsley, Ray K. Jr. - Discussion of Clark's paper.

Time lags to 20, 40, 50, 60, 80 and 100 percent of unit hydrograph runoff were selected for definition of the unit hydrograph shape. For the purpose of assessing the relative merits of each of the aforementioned indexes, three sets of regression equations were developed for estimating the prescribed lags. Two were simple regressions using $L/\sqrt{S_{st}}$ and $L\sqrt{DA/S_{st}}$ separately as independent variables, and the third set was a multiple regression using L, DA, and S_{st} as independent variables for unbiased weighting. Coefficients of determination and standard errors of estimate were computed for all of the derived regression equations. On the basis of similar orders of reliability for all three functions, $L/\sqrt{S_{st}}$ was adopted as the index for use in all further determinations of synthetic unit hydrographs.

105. Using the adopted index referred to in the paragraph above, estimates of time lag T to indicate percentages of the unit hydrograph runoff were derived from the relation:

$T = A\,(L/\sqrt{S_{st}})^b$, where, A and b are regression constants. The adopted constants are listed in table M-19 and can be solved graphically with the curves of plate 52.

TABLE M-19
CONSTANTS FOR LAG FUNCTIONS OF S-CURVE METHOD

Percent Runoff	A	b	$\bar{R}^2$
20	3.30	0.420	0.91
40	5.56	0.368	0.93
50	6.95	0.343	0.89
60	8.83	0.319	0.86
80	14.2	0.278	0.73
100	38.5	0.227	0.71

The factor $\bar{R}^2$ in table M-19 is the coefficient of determination adjusted for degrees of freedom. Note that the higher coefficients of determination apply to the lower percentages of runoff, indicating a stronger relation in this region where it is most needed for definition of the rising limb and the peak of the unit hydrograph.

106. Application of the S-Curve Method for Defining Synthetic Unit Hydrographs. The independent method of synthetic unit hydrographs construction developed in the previous paragraph will hereafter be referred to as the "S-curve" method because the S-curve technique of unit hydrograph construction is a principal feature of the method. Figure 3 on plate 51 shows a typical S-curve. In previous paragraphs the S-curve was described as a dimensionless hydrograph resulting from unterminated uniform rainfall excess. It is, primarily, a mass curve with its dimensionless vertical scale in terms of percent of runoff

and represents the time variation of cumulative runoff of the unit hydrograph. In the development of the method, S-curves were constructed from derived unit hydrographs by accumulation of successive three-hour flows to provide data on time lags to the various percentages of runoff. In application, the same procedure is followed in reverse. The S-curve is first drawn through six points whose positions are computed from the relation between $L/\sqrt{S_{st}}$ and time lags to 20, 40, 50, 60, 80 and 100 percent runoff. The dimensionless 3-hour unit hydrograph is computed from differences between successive 3-hour ordinates of the S-curve. The dimensionless unit hydrograph is smoothed and converted to runoff in cubic feet per second by a conversion factor involving the nominal duration of rainfall period for the unit hydrograph and the drainage area of the basin. Unit hydrographs are commonly applied to rainfall excess amounts in inches and the resulting flow is expressed in c.f.s. For this purpose, the conversion factor is 645 DA/t, where DA is drainage area in square miles and t is the nominal duration in hours of the rainfall period for the unit hydrograph. An example of the procedure for construction of the synthetic S-curve and the unit hydrograph follows:

a. Measurements on quadrangle sheets: drainage area (DA), length of longest water course (L), and the equivalent main stream slope (S_{st}). Assume: DA = 33 sq. mi., L = 8.8 miles, and S_{st} = 0.0142 = 75 ft./mile.

b. Computation of drainage area characteristics: $L/\sqrt{S_{st}} = 8.8/\sqrt{75} = 1.01$.

c. Computation of runoff lags: For $L/\sqrt{S_{st}} = 1.01$, plate 52 indicates S-curve values: t_{20} = 3.3 hrs., t_{40} = 5.5 hrs., t_{50} = 6.9 hrs., t_{60} = 8.8 hrs., t_{80} = 14.5 hrs., t_{100} = 38 hrs.

d. Computation of S-curve and 3-hour unit hydrograph: S-curve is plotted with information found in c. Computations are shown in table M-20 for obtaining the 3-hour synthetic unit hydrograph. S-curve and unit hydrograph are shown on plate 53.

TABLE M-20

SAMPLE COMPUTATION FOR SYNTHETIC UNIT HYDROGRAPH

Time in Hours	% of Ultimate R.O. Volume from Plotted S-curve	3-Hr. Unit Hydrograph Unadjusted %	Adjusted %	c.f.s.
0	0	0	0	0
3	18.5	18.5	18.5	1,310
6	43.0	24.5	24.5	1,740
9	60.8	17.8	17.8	1,260
12	72.2	11.4	11.6	820
15	81.0	8.8	8.2	580
18	87.1	6.1	6.1	430
etc.	etc.	etc.	etc.	etc.
38	100.0	0	0	0
		100.0	100.0	7,095

Basins having complex drainage patterns with two or more confluent streams of different characteristics, or having odd shapes are best treated by dividing them into several subareas and deriving separate synthetic unit hydrographs for each subarea. The component unit hydrographs are combined with due regard to travel time from their points of origin to the point of basin outflow.

107. Comparison of Procedures for Deriving Synthetic Unit Hydrographs. As a quality check on the S-curve method, a comparison was made between the constants derived empirically for the Delaware basin and the constants published for the Taylor-Schwarz method. A check was also made by comparing synthetic unit hydrographs obtained by the S-curve method and the Taylor-Schwarz method. The constants of the Taylor-Schwarz method permit computation of peak and lag (time to peak) for the synthetic unit hydrograph. Table M-21 compares Taylor-Schwarz published constants of the functions for estimating lag to peak with empirically derived constants of these functions for Delaware basin streams.

TABLE M-21

COMPARISON OF DELAWARE BASIN AND DERIVED TAYLOR-SCHWARZ CONSTANTS

Source	$c' = A_1(S_{st})^{b_1}$		$m' = A_2(LL_{ca})^{b_2}$	
	A_1	b_1	A_2	b_2
Taylor-Schwarz	0.60	-0.500	0.212	-0.36
Delaware River Study:				
All areas	0.57	-0.459	0.212	-0.36
Areas less than 25 sq. mi.	0.57	-0.389	0.308	-0.68

The constants are in reasonable agreement for overall general relations applicable to all areas in the Delaware basin. For areas smaller than 25 sq. mi., however, the Delaware basin constants differ significantly from those from the Taylor-Schwarz method. The same general conclusions apply to the functions for estimating the synthetic unit graph peak.

108. Synthetic unit hydrographs computed by the S-curve method are compared with derived unit hydrographs and Taylor-Schwarz synthetic unit hydrographs for 14 randomly selected areas on plates 54 and 55. In most cases it is seen that the results of the two methods approximate each other fairly well, with the S-curve method generally providing a slightly better reproduction of the derived unit graph. It is to be noted that any apparent superiority of the S-curve method for Delaware basin streams probably derives primarily from its application to the same streams from which data were used in defining the basic relations of the method. It is not known to what extent this method could be used to reproduce unit hydrographs derived for areas outside the Delaware basin. The generalizations should be checked for applicability before being used for such areas. The S-curve method was adopted for use in the present study primarily because of the ease and speed with which the procedure could be used in the construction of synthetic unit hydrographs rather than because of any actual or implied superiority in accuracy over other methods for deriving synthetic unit hydrographs. It is apparent that the S-curve method, to the degree of its present development, can be improved. The S-curve needs additional definition in the ranges 0-20 percent and 80-100 percent to permit better shaping of the rising-limb and tail of the unit hydrograph. However, these ranges are not too critical, since they have little effect on the timing and magnitude of the unit hydrograph peak. While the error of estimating the 80 percent and 100 percent time lags appears large, this is due, no doubt, to the lack of precise criteria in the original unit hydrograph derivations for establishing the base length of the net flow hydrograph. It is believed that a criterion such as time lag to 100 percent runoff given by $L/\sqrt{S_{st}}$ of the S-curve method would make base lengths more consistent without affecting the peak of the unit hydrograph. In spite of its foibles, the S-curve method permits rapid and direct computation of synthetic unit hydrographs of any desired duration for areas up to 1,000 square miles in the Delaware River basin. These hydrographs have been found to be equally as usable as any that can be obtained by other known methods currently in use. Furthermore, the method requires computation of only one basin index, $L/\sqrt{S_{st}}$, which is used with a single set of curves to define time lags to 20, 40, 50, 60, 80 and 100 percent of unit hydrograph runoff.

109. STREAMFLOW ROUTING THROUGH NATURAL VALLEY STORAGE. Procedures for routing streamflows are necessary to complete analysis of the hydraulics of the natural waterways of the basin. The basic

hydrologic functions inherent in routing procedures are the time of travel and the effect of natural valley storage on the inflow-outflow relations in any given reach of the stream. The translation of steady low inbank flows is dependent primarily on the time of transit and is used to determine the amounts of release required from upstream reservoirs to maintain specific flows in the lower reaches of the river. Flood flows are routed through natural valley storage for the reconstitution of past flood hydrographs, for the determination of main stem hydrographs for hypothetical design floods, and for the determination of modified hydrographs resulting from upstream reservoir storage. In such routings relations derived from an analytical evaluation of the effects of storage in modifying discharges of record are used.

110. Routing of Low Flows. The Office of the River Master, at Milford, Pennsylvania, under the direction of the U. S. Geological Survey, has developed times for transit of water for the upper Delaware River basin in connection with controlled releases from New York City's water supply reservoirs. Data secured from the River Master's office, together with information from this study, served as a basis for determination of travel times from the various sources of controlled supply to various downstream points on Delaware River and its principal tributaries. These travel times are shown in table M-22.

TABLE M-22
LOW FLOW TRAVEL TIMES - DELAWARE RIVER BASIN

Stream	Reach Limits	Distance (miles)	Time of Travel (hours)
W.Br.Delaware R.	Cannonsville to Hancock	16.9	18
E.Br.Delaware R.	Pepacton to Hancock	27.6	20
Lackawaxen R.	Wilsonville to Barryville	12.6	4
Neversink R.	Neversink to Godeffroy	32.0	18
	Godeffroy to Port Jervis	8.7	6
Lehigh R.	Stoddartsville to Tannery	15.5	5
	Tannery to Walnutport	36.0	15
	Walnutport to Bethlehem	22.5	16
	Bethlehem to Easton	11.0	10
Schuylkill R.	Pottsville to Berne	27.1	8
	Berne to Pottstown	41.6	15
	Pottstown to Philadelphia	45.0	27
Delaware R.	Hancock to Barryville	53.0	26
	Barryville to Port Jervis	23.0	10
	Port Jervis to Montague	18.3	4
	Montague to Tocks Island	28.7	22
	Tocks Island to Belvidere	20.2	9
	Belvidere to Easton	14.2	4
	Easton to Riegelsville	8.5	2
	Riegelsville to Trenton	40.3	14

111. Routing of Flood Flows. Flood routing studies were made for Neversink, Lehigh, Schuylkill, and Delaware Rivers. For the purpose of defining the procedures for routing of flood hydrographs used in this report, detailed information is given only for the main stem of Delaware River. Similar methods were used on the tributary streams. Several well-known routing procedures were tested and the coefficient method by Gilcrest 14/ was finally adopted for use in this survey as the most expedient with respect to accuracy and ease of computation. From an analysis of past floods in the Delaware River basin, it appears that the runoff regimen has been such that a disproportionate part of the inflow into routing reaches was generated by rainfall within the reaches themselves. Also a very large proportion of the local inflows were ungaged, especially in the upper reach of the basin above Port Jervis, New York. This condition caused the relations of valley storage to flow to be rather complex and required considerable detailed study of past floods.

112. Routing Reaches. The number of reaches on Delaware River was limited by the number of points at which stage-discharge relations could be determined. However, due to the relatively long distance between the Montague and the Belvidere gaging stations, and between the Riegelsville and the Trenton gages, it was found necessary to divide each of these into two reaches. Accordingly, the Delaware was divided into the following eight reaches:

a. West Branch Delaware River from Hale Eddy and East Branch Delaware River from Fishs Eddy to Barryville on Delaware River.

b. Delaware River from Barryville to Port Jervis.

c. Delaware River from Port Jervis to Montague.

d. Delaware River from Montague to Tocks Island.

e. Delaware River from Tocks Island to Belvidere.

f. Delaware River from Belvidere to Riegelsville.

g. Delaware River from Riegelsville to Lumberville.

h. Delaware River from Lumberville to Trenton.

14/ Gilcrest, B. R., "Flood Routing," Chap. X of Engineering Hydraulics (Hunter Rouse, Editor), New York, Wiley, 1950.

113. Relation of Valley Storage to Discharge. The relation of valley storage to discharge (weighted flow) within each reach was established by the construction of storage loops from observed flows of the 1942 and 1955 floods. The procedure is based on the assumption that the ratio of valley storage within a reach to a weighted flow factor determined from both inflow and outflow is constant, and is dependent upon the physical shape of the valley within the reach. It follows that the ratio of any increment of valley storage to the corresponding increment of the weighted flow factor is also constant. The basic equation is written

$$K = \frac{.5\Delta t((I_2 + I_1) - (O_2 + O_1))}{X(I_2 - I_1) + (1 - x)(O_2 - O_1)} \quad .$$

Values of X were assumed, and tabulated values of the numerator and the denominator were accumulated and plotted. The value of X giving the curve most nearly approximating a straight line was taken as the correct value to use in weighting the flow. K was computed from the reciprocal of the slope of the curve (the numerator of fraction was plotted along the abscissa).

114. Adopted Flood Routing Procedures. Trial routings were made using Gilcrest's method in which the routing coefficient c, is equal to $\Delta t/K$. Unit hydrographs for the ungaged areas in each reach were developed from synthetic procedures described in preceding paragraphs 101 to 108. Inflows for the local areas were determined by applying rainfall excesses to the synthetic unit hydrographs and adding the flows at the lower end of the reach. When Δt equals 2KX the Gilcrest routing technique produces the same results as the so-called "Muskingum routing methods."15/ Since it was not always possible to select Δt equal to 2KX, a check was made to determine the acceptability of this procedure when Δt varied from 2KX by small amounts. It was found that the routed results were within the acceptable limits of error when compared with results obtained by use of the Muskingum method. A check was made also of the ratios of incremental storage to corresponding weighted flow (K values) by plotting the peak discharges for the 1942 and 1955 flood profiles against the valley storage beneath them as determined from measured valley cross sections. Sections were available at about two-mile intervals for the reaches from Port Jervis to Montague and from Montague to Tocks Island. The checks show that the K values for the two reaches computed by the two independent methods agreed reasonably well and were, therefore, considered adequate for use in flood routing.

15/ U. S. Army, Corps of Engineers, Engineer School, "Engineering Procedure as Applied to Flood Control by Reservoirs with Reference to Muskingum Flood Control Project," Fort Belvoir, Va., Appendix 5, 1936.

115. Routing Constants. The routing constants in table M-23 represent values of $\Delta t/K$ (routing coefficient) for Δt = 3 hrs. in all reaches. After the routing constants were determined, flood routing was carried on by tabular solution of the routing equation.

116. RECONSTITUTION OF FLOOD HYDROGRAPHS OF RECORD. The 23-24 May 1942 and 18-20 August 1955 flood hydrographs for stations on Delaware, Lehigh, and Schuylkill Rivers were reconstituted by coefficient routing procedures. These reconstituted hydrographs compare favorably with the actual observed hydrographs at these stations. A comparison of the observed and reconstituted hydrographs for Delaware River at Barryville, Port Jervis, Montague, Belvidere, Riegelsville and Trenton is shown on plates 56 and 57.

117. ROUTING OF MODIFIED FLOWS. Routing of the effects of individual reservoirs or system of reservoirs on flood discharges at downstream river reaches was accomplished by the Gilcrest coefficient method. In order to cover adequately the general range of flood flows on Delaware River and its tributaries, four floods of record were selected. Although an attempt was made in choosing the floods to cover generally the entire range from moderate to high flows, it was not possible to select them at equal intervals because of the limited data available for some of the stations. The four floods finally selected are 22 September 1938, 23-24 May 1942, 12 December 1952 and 19-20 August 1955. For purposes of planning and preliminary design of flood control and multiple-purpose projects, a flood greater than any that has been experienced in the basin was computed using a hypothetical storm. This storm and the resultant flood, called the "Basin Project Flood" are fully discussed in paragraphs 132 to 135 inclusive.

118. The Delaware River basin was divided into a large number of smaller subareas, where possible, corresponding to the areas above proposed dam sites. Prior to routing the subarea contribution of the four record floods and the "Basin Project Flood" to points downstream, the individual hydrographs for each basin subarea were corrected for the effects of storage from existing reservoirs. Three reservoirs, which have had sufficient storage available for reducing flood peaks downstream are Wallenpaupack Reservoir on Wallenpaupack Creek near Wilsonville, Pennsylvania, Pepacton Reservoir on the East Branch of Delaware River at Downsville, New York, and Neversink Reservoir on Neversink River at Neversink, New York. Flood hydrographs of inflow into each reservoir were determined from synthetic unit hydrographs and rainfall excesses were derived from the actual storm, except for Wallenpaupack Creek where hourly reservoir elevations were available for the flood period and were used to determine the inflow hydrographs. A general map of the Delaware River basin showing the eight routing reaches on the main stem, and the 27 individual subareas above Trenton is given on plate 58. A typical example of the routing results which gives the individual contributions of natural flows for

TABLE M-23

FLOOD ROUTING CONSTANTS

Routing Reach	Length of Reach (miles)	"K" determined from storage loop		Adopted "K" (hours)	Adopted "C" (t=3 hrs.)
		DELAWARE RIVER			
		1955 Flood	1942 Flood		
D-1	51.3	5.0	5.0	5.0	0.6
D-2	24.5	3.7	3.1	3.3	0.9
D-3	8.0	3.0*	3.1*	3.0*	1.0*
		5.6**		5.0**	0.6**
D-4	29.0)	11.1	11.2	5.5)-11.0	0.55
D-5	20.0)			5.5)	0.55
D-6	22.7	4.8	4.8	5.0	0.6
D-7	19.4)	8.0	7.5	3.5)- 7.5	0.85
D-8	20.9)			4.0)	0.75

* For flows < 138,000 cfs

** For flows > 138,000 cfs

Routing Reach	Length of Reach (miles)	"K" determined from storage loop		Adopted "K" (hours)	Adopted "C" (t=3 hrs.)
		LEHIGH RIVER			
		1955 Flood	1952 Flood		
L-1	11.0	-	-	2.5	1.0
L-2	22.4	4.0	4.0	4.0	0.75
L-3	36.0	5.0	-	5.0	0.6
L-4	15.5	2.5	-	2.5	1.0
		SCHUYLKILL RIVER			
		1955 Flood	1952 Flood		
S-1	24.4	6.3	6.4	6.3	0.45
S-2	40.3	9.0	9.0	9.0	0.3
S-3	44.1	11.0	11.1	11.0	0.25

each of the 27 subareas for the August 1955 flood at Trenton is shown on plate 59. In most cases reservoir capacity tentatively allocated for flood control in each of the proposed projects was sufficient to retain 100 percent of the runoff of all floods up to and including the "Basin Project Flood." Therefore, the effect of any reservoir on downstream river reaches was readily determined from the above flood routings. In projects where allocated flood control capacities were not sufficient to effect total retention the flood hydrographs were routed through reservoir storage and the resulting releases were routed individually to downstream points.

119. ROUTING THROUGH RESERVOIR STORAGE. In order to compute the reservoir stage, storage and outflow which would result as a flood wave is passed through storage in a reservoir, use is made of the basic routing equation wherein the total quantity of inflow during a given period of time minus the total quantity of outflow during the same period equals the change in the volume of water stored in the reservoir. The following assumptions were made in order to simplify the computing procedure:

a. That the reservoir surface is level at all times and, therefore, the backwater effects on the reservoir surface could be neglected.

b. That channel storage between the variable location at which inflow merges with the reservoir level and the upstream inflow gage is relatively minor and could be neglected.

Since widths, depths and volumes of the reservoir are generally great in comparison to that of the inflowing stream, these assumptions will generally result in only negligible errors. It may be found advisable to adjust the reservoir routing procedure for the effect of these assumptions at certain reservoir sites, particularly those having long, narrow lakes containing limited storage volumes. The corrections, when necessary, are made using backwater computations. By selecting a time interval short enough so that both inflow and outflow may be considered linear functions of t within each time interval, the routing equation may be written as:

$$(t_2 - t_1)\left(\frac{I_2 + I_1}{2} - \frac{O_2 + O_1}{2}\right) = S_2 - S_1$$

Where, t = time,
I = inflow,
O = outflow, and
S = storage.

Solution of this equation is dependent on the relations involving storage and outflow. The storage-elevation curve and the outflow rating curve, determined from physical characteristics of the reservoir and the outlet respectively, permit the evaluation of the routing equation. Several reservoir routing methods were investigated which utilize the inflow-storage-outflow relations. The following method 16/ was adopted for use because of its ease of application and accuracy of results. The storage equation was rewritten, substituting t for $(t_2 - t_1)$ and transposing the unknown values to the right side.

$$(I_1 + I_2) + \left(\frac{2S_1}{t} - O_1\right) = \left(\frac{2S_2}{t} + O_2\right)$$

Based on the outflow rating curve and on the reservoir capacity curve, a plot of $2S_2/t + O$ versus O was made for various pool levels. The inflow hydrograph was routed through gross reservoir storage employing this plot and a tabular computing procedure. On occasion it was found expedient to route flood hydrographs through reservoirs using the Gilcrest technique previously described in paragraphs 111 to 115 inclusive. In order to apply this procedure it is necessary that the discharge-storage-relation be linear; that is, the slope, "K", of the discharge-storage-relation be constant. If this relation is not linear, then it becomes necessary to route the flows through several increments varying the slope "K" so as to approximate the discharge-storage-relation incrementally. Results were found to be in close agreement for the various reservoir routing methods used.

120. SURFACE WATER AVAILABILITY STUDIES. A knowledge of availability of water, where it comes from, how much there is, and what is required for its control to meet a variety of needs is essential to the optimum planning for water resource development with regard to where to build, how big to build and how to operate a system of water control structures. For these purposes it was necessary to develop procedures; (a) to evaluate where and how much water is available in the Delaware basin as determined from long term average flows at key points in the basin, and (b) to evaluate flow-storage relations as bases for flow control studies. The latter relations define the storage capacities needed to maintain preassigned flows and the upper limits of potential ultimate maximum development in tributary subbasins. For estimation of similar information in areas where flow data are lacking it was necessary, also, to generalize the derived relations.

16/ Johnston and Cross - Elements of Applied Hydrology - chapter 7, Article 7-3, pp. 167-171.

121. Mass curves of mean monthly flow were analyzed to determine storage required to maintain the 32-year mean flows and lesser flows. A standard analytical procedure was used. A typical mass curve with an expanded section in the low-flow region is shown on plate 31. Graphical analyses were used to locate approximate dates of extreme departures of the observed mass curve from the mass curve of the indicated uniform flow, and volume computations were made with the aid of mass curve tabulations to find the extreme departure in each case. Plots of flow versus required storage were prepared for each of the 43 stations listed in table M-24. These relations are shown graphically for selected stations on plates 60 to 62 inclusive. In conjunction with the examination of storages required to maintain various flows at a station, it is important to know how long it will take to refill a reservoir to a preassigned capacity from the time its contents begin to be depleted for maintenance of a specified flow. This period of depletion and refilling is designated as the carry-over period. For purposes of the present study it is the longest of such periods associated with a particular flow during the period of record used for the analysis. Curves of carry-over versus flow are also shown on plates 60 to 62, inclusive.

122. Generalization of Flow-Storage Relations. As described above, mass curves were analyzed to find the storages required to maintain various flows at certain streamflow stations in the Delaware basin. Because of insufficient data it was not possible to make these mass curve analyses at all points of interest. It was expedient, therefore, to make some generalizations with the derived empirical flow-storage relations between flow and storage so that synthetic flow-storage curves could be constructed from the drainage area data on the basis of homogeneity with other areas where derived relations were available. Relations of mean flow and storage to drainage area appear to be fairly well defined. These relations permit estimates to be made of the upper limit of storage and the long-term average flow to be expected from an area with the indicated ultimate storage development. Plate 63 shows these latter relations.

123. Of the data for the 43 stations listed in table M-24, 17 were based on actual 32-year records for the period 1923-1954 and 19 were adjusted to the same standard period. Generalizations of ultimate flow and storage versus drainage area were based on the 36 stations for which 32 years of flow information, either observed or estimated, was available. The symbols shown on plate 63 indicate by solid circles the 17 stations having actual 32-year records. These points were given greatest weight in establishing the trend lines. The 19 stations whose records were adjusted to 32 years are plotted with symbols indicating the approximate period of observed record as described in the legend. These plotted points were used as general guides in establishing the trend lines but with lesser weight than the solid circles. Finally, the remaining seven stations whose records

TABLE M-24

MEAN FLOW AND REQUIRED STORAGE FOR 43 STATIONS

Stream and Station	D.A.	Observed Record Used			Ultimate Flow		Ultimate Storage		Nat. Minimum Flow	
	sq.mi.	Start	End	Yrs.	cfs	csm	1000 af	1000 af/sq.mi.	cfs	csm
<u>Main Stem Delaware River, Penna. and New York Tributaries (except Lehigh R. & Schuylkill R.)</u>										
Mill Brook at Arena	25	1937*	1954	18	57	2.28	52	2.08	5	.16
E.Br.Delaware R. at Downsville	373	1941	1953	13	720	1.93	635	1.70	60	.16
L.Beaver Kill at Livingston Manor	19.8	1925*	1954	30	46	2.32	47	2.37	5	.19
Beaver Kill at Cooks Falls	241	1923	1954	32	562	2.33	545	2.26	50	.19
E.Br.Delaware R. at Fishs Eddy	783	1923	1954	32	1,650	2.11	2,171	2.77	150	.16
Cold Spring Brook at China	1.5	1935*	1954	20	2.7	1.77	3	1.92	0.2	.16
W.Br.Delaware R. at Hale Eddy	593	1923	1954	32	1,050	1.77	935	1.58	70	.16
Middle Creek at Hawley	78.4	1945*	1954	10	121	1.54	165	2.10	10	.15
Lackawaxen R. at Hawley	290	1938*	1943	17	494	1.70	659	2.27	30	.15
Wallenpaupack Cr. at Wilsonville	228	1923	1954	32	350	1.54	507	2.22	5	.02
Delaware R. at Port Jervis	3,076	1923	1954	32	5,670	1.84	5,880	1.91	500	.16
Neversink R. at Godeffroy	302	1937*	1954	18	630	2.09	642	2.13	50	.16
Bush Kill at Shoemakers	112	1923	1954	32	234	2.09	231	2.06	15	.29
McMichaels Cr. nr Stroudsburg	64.4	1923	1938	16	111	1.72	117	1.82	20	.16
Delaware R. at Belvidere	4,535	1923	1954	32	8,350	1.84	8,700	1.92	720	.16
Delaware R. at Riegelsville	6,328	1923	1954	32	11,550	1.82	13,900	2.20	1,830	.29
Tohickon Cr. at Pipersville	97.4	1936	1955	20	146	1.50	142	1.46	5	.05
Delaware R. at Trenton	6,780	1923	1954	32	12,240	1.81	13,800	2.04	2,000	.29
Brandywine Cr. at Chadds Ford	287	1923	1953	31	393	1.37	428	1.49	90	.31
Brandywine Cr. at Wilmington	314	1948*	1954	7	437	1.39	477	1.52	90	.30
<u>Lehigh R. & Schuylkill R.</u>										
Lehigh R. at Stoddartsville	91.7	1944*	1954	11	182	1.98	268	2.92	20	.23
Lehigh R. at Tannery	322	1929*	1954	26	662	2.06	954	2.96	100	.23
Pohopoco Cr. at Parryville	109	1941	1955	15	211	1.94	179	1.64	30	.26
Aquashicola Cr. at Palmerton	76.7	1940	1955	16	159	2.07	170	2.22	20	.23
Lehigh R. at Walnutport	889	1947**	1954	8	1,764	1.98	2,730	3.07	220	.25
Jordan Cr. at Allentown	75.8	1945	1955	11	123	1.62	122	1.61	20.	.25
Lehigh R. at Bethlehem	1,279	1923	1954	32	2,345	1.83	3,323	2.60	400	.25
Schuylkill R. at Pottsville	53.4	1944*	1954	11	104	1.95	178	3.33	10	.26
Schuylkill R. at Landingville	133	1947*	1952	6	256	1.92	470	3.53	30	.26
L.Schuylkill R. at Tamaqua	42.9	1923	1954	32	94	2.19	186	4.34	10	.26
Schuylkill R. at Berne	355	1948*	1954	7	687	1.94	1,346	3.79	90	.26
Tulpehocken Cr. at Reading	211	1951*	1954	4	302	1.43	504	2.39	50	.26
Schuylkill R. at Pottstown	1,147	1932*	1954	23	1,941	1.69	2,433	2.12	300	.26
Perkiomen Cr. at Graterford	279	1932*	1954	23	394	1.41	494	1.77	30	.11
Schuylkill R. at Philadelphia	1,893	1932*	1954	23	3,020	1.60	3,357	1.77	350	.18
<u>New Jersey Tributaries</u>										
Flat Brook at Flatbrookville	65.1	1924	1954	31	111	1.70	110	1.69	10	.20
Paulins Kill at Blairstown	126	1923	1954	32	195	1.55	295	2.34	25	.16
Pequest R. at Pequest	108	1923	1954	32	159	1.47	180	1.67	20	.20
Beaver Brook at Belvidere	36.2	1923	1954	32	53	1.46	74	2.04	10	.29
Musconetcong R. at Lake Hopatcong	25.6	1929*	1954	26	44	1.72	64	2.50	10	.42
Musconetcong R. at Hackettstown	70	1923	1954	32	121	1.73	169	2.41	30	.42
Musconetcong R. at Bloomsbury	143	1923	1954	32	232	1.62.	313	2.19	60	.42
Manantico Cr. at Millville	22.3	1932*	1954	23	37	1.66	39	1.75	10	.40

* Record adjusted to 32 years.
** Record adjusted to 26 years.

were not adjusted to the standard period are plotted only as a matter of relative information. The short term unadjusted stations tend to plot above the flow trend line and below the storage trend line indicating that shorter periods of record give erroneously high estimates of the long term average flow and erroneously low estimates of ultimate storage because their records do not reflect the drought of the thirties.

124. Since runoff rates vary in different parts of the basin adjustment is made for this variation in using the curves. The positions of the solid circles (representing original 32-year records) with respect to the average trend line indicate the relative level of runoff in that basin with respect to the average. The geographic distribution of the 32-year stations is sufficiently broad so that there is at least one of these in each of the major tributary subbasins. These are easily located on plate 63 from information given in table M-24. The procedure for finding ultimate flow for a dam site in the Brandywine watershed, for example, would be to find the point representing Chadds Ford, D.A. = 787 sq. mi. ultimate flow = 392 c.f.s. A line drawn through this point and parallel to the average trend line then represents any subbasin in the Brandywine watershed. An alternate, but somewhat more lengthy procedure for finding ultimate flow is to draw the outline of the drainage area on a map of average annual runoff (plates 41A and B of the USGS report mentioned in paragraph 67) and compute the average basin flow by planimetering the runoff contours. The ultimate storage requirement may then be computed as a percentage of the annual runoff.

125. Results from either method are generally in close agreement. The drainage area relations were adopted for use in this study, primarily because of the simplicity and directness of the computations. Since estimates of ultimate flow and storage obtained by this method are used only for general survey and planning purposes, they are adequate for preliminary studies involving estimates of project yields. It is to be noted that final project yields are refined by reservoir operation studies using actual flow records where possible or synthetic records where actual flows are not available.

126. Derivation of Synthetic Flow-Storage Relations. Estimates of storage requirements for lesser flows were made for ungaged areas with the aid of the dimensionless curves shown on plates 64 through 66. The curves on these plates are similar to the flow-storage curves on plates 60 to 62, inclusive, except that both vertical and horizontal scales have been reduced to percentages of ultimate flow and storage, respectively. Construction of a synthetic flow-storage curve from the general relations is accomplished by first obtaining estimates of ultimate flow and storage from the appropriate curve on plate 63. With these estimates as the 100 percent values, the synthetic flow storage curve is constructed from the pertinent curve on plates 64 through 66.

127. The derivation of flow-storage relations and generalization of these relations for ungaged portions of the basin were accomplished in the manner described above. It is now of interest to examine the significance of this information with regard to planning use. Ultimate flow represents the upper limit of uniform sustained flow that can be obtained from an area with the indicated ultimate storage. The term "ultimate" in this sense implies maxima of flow and storage associated with extreme departures of the mass curve of natural flow from the mass curve of mean flow for the period of record (32 years in this case). Storage in excess of the ultimate will not provide a higher uniform yield unless subsequent history modifies these extremes by more severe droughts and floods than were experienced during the period studied. It is anticipated, however, that future changes in the flow regimen will not seriously affect the flow-storage relations for the lesser flows in the planning range. In practice it is rarely possible for physical, economic or political reasons to find a sufficient number of reservoir sites with adequate capacities to provide the fullest degree of regulation. On the other hand, storage in excess of the ultimate storage requirements may be in order for some types of developments if provision is made for diversion of flow into the area from outside sources. Storage requirements to sustain any flow up to the ultimate may be read directly from the flow-storage curve or conversely, flows obtainable with given storages may be found. It is emphasized that no adjustments for evaporation or seepage loss have been made at this time since these losses are relatively small compared to the total storage volumes involved.

128. Optimum Flow-Storage Development. On the dimensionless flow-storage curve, 100 percent on either scale represents ultimate development for the site. Percentage-wise, flow and storage are equal at ultimate development. If they were, in fact, equal at lesser degrees of development, the dimensionless flow-storage curve would be a straight line, with percent flow being equal to percent storage for any storage. Such is not actually the case but this hypothetical straight line flow-storage relation permits an interesting analysis of maximized marginal flow gains or benefits. Refer to plate 67. Where the 45° line represents the base flow storage ratio of 1.00, vertical departures of the flow-storage curve above this line may be regarded as marginal flow benefits per unit of storage. These departures of flow from the 45° line are plotted as the lower curve on plate 67 and are designated "marginal flows." It is seen that maximum marginal flow benefits occur at point A. This point is found on the flow-storage curve by drawing a 45° line tangent to the curve. The point so located is designated the "knee" of the flow-storage curve and, within the limiting assumptions, indicates a preliminary estimate of storage for optimum yield. Curves of "knee" storage versus drainage area are shown on plate 68.

129. Operational Significance of Flow-Storage Relations. Estimates of flow available with given storage capacities can be assured operationally only when the indicated storage is allocated without reservation to flow regulation. Storage requirements for other uses may be included without prejudice to estimated flows when operation for other uses does not conflict with normal operation for flow regulation. Estimated flows for given storages are assured minimum flows. With any storage capacity (other than the ultimate for the site) flows in excess of the indicated value may be experienced at such times as the reservoir is filled to the capacity provided for flow regulation purposes. Regulation of flow to magnitudes indicated by the flow-storage relations thus assures that the flow could have been equal to or greater than the indicated flow at all times had such a reservoir existed in the past and, further, that the reservoir capacity assigned to this use would have been empty only once during the portion of the record studied. Operation of Hawk Mountain Reservoir near Fishs Eddy, New York is illustrated on plate 69 for a controlled yield of 730 c.f.s. with a capacity of 290,000 acre-feet. The use of synthetic relations for computation of yield is indicated in sample computations shown on the plate. Monthly values of observed flow, regulated flow, and reservoir contents are shown for the drought period from January 1928 to December 1934. The regulated flow is never below 730 c.f.s. and after the initial filling the reservoir is empty only once (February 1931) during the entire period of operation.

130. Application of Flow-Storage Procedure. The flows and associated storage requirements presented above were based on analysis of mean monthly flows and consequently are applicable only in general planning studies where monthly averages suffice. In the present study the procedures described were applied to potential reservoirs for preliminary allocation of water supply storage and for estimation of project yields. Particular periods of interest are analyzed separately in greater detail (daily or hourly) for specific applications involving droughts and floods where a shorter time period is more critical.

131. The U. S. Geological Survey made studies 17/ on storage required to maintain various flows in which frequency was used as a parameter in association with reservoir yields. In these studies charts and tables were presented for 18 stream gaging stations in the Delaware basin showing the 2, 5, 10 and 25-year yields in million gallons per day per square mile for a range of storage from 0 to 50 million gallons per square mile. In contrast, the water availability

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17/ Studies completed in July 1958 in connection with preparation of a report on Water Resources of the Delaware River Basin and Its Service Area.

studies presented in this appendix indicate continuous uniform yields throughout the entire 32-year study period without regard to frequency. Since the projection periods for estimating future water demands are somewhat extended, it is considered conservative for long range planning to provide, within tolerable limits, for at least the worst drought of record.

SECTION VI - HYPOTHETICAL FLOODS AND DESIGN CAPACITIES

132. BASIN PROJECT FLOODS. In order to satisfy planning needs for "typical" or "project" floods, a basin project flood was developed for the Delaware River basin above Trenton, New Jersey and also for the Schuylkill River basin above Philadelphia, Pennsylvania. These floods were prepared substantially in accordance with the established procedure for the determination of Standard Project Floods.18/

133. The preliminary estimates of probable maximum precipitation in the basin by the Hydrometeorological Section of the U. S. Weather Bureau 19/ were given careful consideration in establishing the storm rainfall for the basin project floods. Storm pattern A from the estimates of probable maximum precipitation, when placed over the basin outline in accordance with geographical limitations on transposition and rotation, was found to produce the probable maximum average rainfall depth over the basin. The 72-hour basin-average rainfall depth for that storm pattern, obtained by planimetering the isohyets within the basin, was further adjusted by the percentage ratic (92 percent) for the positioning of the maximum center of the pattern. Basin-average depth for various subdurations of the probable maximum precipitation was then secured by applying the percentage values determined by the U. S. Weather Bureau studies of probable maximum depth-duration area values for storms centered at latitude 41°N, and longitude 75°W. The breakdown of probable maximum precipitation depths thus derived for the Delaware River basin above Trenton is given in table M-25.

18/ Civil Works Engineer Bulletin No. 52-8, Standard Project Flood Determinations, Office, Chief of Engineers, Department of the Army, 26 March 1952.

19/ Letter from Chief, Hydrometeorological Section, U. S. Weather Bureau to Office, Chief of Engineers, Preliminary Estimates of Probable Maximum Precipitation for Delaware River above Trenton, N. J. (5,000 and 7,000 sq. miles), 19 November 1956.

TABLE M-25
COMPARISON OF PRECIPITATION DEPTH-DURATION VALUES
FOR PROBABLE MAXIMUM STORM AND BASIN PROJECT STORM

	Duration (Hours)						
	6	12	18	24	36	48	72
Probable Maximum Accumulated Precipitation (inches)	5.51	7.92	9.24	10.32	11.30	11.65	11.99
Basin Project Accumulated Precipitation (inches)	3.24	3.72	4.01	4.17	4.83	4.95	5.21
Percentage B.P.P. is of P.M.P.	58.6	47.0	43.5	40.5	42.6	42.5	43.5

134. Delaware River Basin above Trenton, New Jersey. A comparison of storm pattern A with the record storms in the vicinity of the Delaware basin revealed that this storm pattern was apparently the same as that of the May 1942 storm and that the total storm isohyets had been increased by 150 percent to secure the probable maximum precipitation. Accordingly, the actual May 1942 storm pattern, transposed without reduction of the average basin depths for the positioning of the maximum center of the pattern, was adopted as a basis for deriving the basin project flood above Trenton. The center of the adopted May 1942 storm pattern was transposed 22.5 miles northeast and rotated 6 degrees counterclockwise, which is well within the geographical limitations established by the Weather Bureau for the probable maximum storm transposition. Plate 70 shows the isohyetal map of the storm after transposition and rotation. After planimetering the isohyets within the basin, the average depths for various subdurations were computed in accordance with criteria established for determination of Standard Project Floods. The basin project precipitation depth for various durations for the Delaware River basin is shown on table M-25. The isohyetal average of the basin project storm precipitation was computed for each of 27 subareas and reduced to storm runoff by using an initial loss of 0.5 inch and infiltration loss of 0.05 inch per hour. Rainfall excesses were then applied to unit hydrographs for the subareas and the resulting flood hydrographs were routed to points downstream on the main stem of Delaware River in accordance with routing procedures outlined in paragraphs 111 to 117 inclusive. The sum of the routed flows produced the basin project flood hydrographs at points on the main stem between Barryville, New York and Trenton. Table M-26 gives the peak discharges and volumes of the basin project flood for principal tributaries and main stem stations. Maximum peak discharges of record are included in table M-26 for purposes of comparison.

TABLE M-26

DATA ON BASIN PROJECT FLOOD FOR TRIBUTARIES AND MAIN STEM STATIONS

Stream	Station	Maximum Record Peak		Basin Project Flood			
		Date	Discharge (cfs)	Peak Discharge* (cfs)	Peak Discharge* (cfs/sq.mi.)	Volume ** inches	Volume ** ac.ft.
W.Br.Delaware R.	Hale Eddy	10 Oct. 1903	46,000	34,000	58.0	3.03	96,700
E.Br.Delaware R.	Fishs Eddy	9 Oct. 1903	70,000	78,500	100.2	4.15	174,800
Delaware R.	Barryville	19 Aug. 1955	130,000	193,500	95.6	3.96	430,500
Lackawaxen R.	Hawley	19 Aug. 1955	51,900	44,400	153.1	3.79	59,100
Delaware R.	Port Jervis	19 Aug. 1955	233,000	311,500	101.3	3.91	647,400
Neversink R.	Godeffroy	19 Aug. 1955	33,000	18,100	59.9	1.79	29,100
Delaware R.	Montague	19 Aug. 1955	250,000	338,300	97.2	3.63	692,000
Delaware R.	Belvidere	19 Aug. 1955	273,000	321,000	70.8	3.66	892,500
Lehigh R.	Bethlehem	23 May 1942	92,000	133,900	104.7	4.69	327,800
Delaware R.	Riegelsville	20 Aug. 1955	340,000	423,800	67.0	3.79	1,287,300
Delaware R.	Trenton	20 Aug. 1955	329,000	417,200	61.5	3.59	1,313,200
Schuylkill R.	Philadelphia	4 Oct. 1869	135,000	192,000	101.4	5.58	564,000
Brandywine Cr.	Wilmington	19 Aug. 1955	17,800	48,200	153.5	5.25	88,000

* For Basin Project Flood only and not to be confused with the peak discharge of the project flood from the sub-area above each station.

** Storm runoff, base flow not included.

135. Schuylkill River Basin above Philadelphia, Pennsylvania. The basin project storm adopted for use in the Schuylkill basin was based on a transposition of the storm of 20-24 August 1933. The storm center near York, Pennsylvania, was moved 49 miles northeast and rotated 55 degrees counterclockwise so that maximum rainfall occurred over the basin above Philadelphia. Plate 72 shows the isohyetal map of the storm after transposition and rotation. Flows on Schuylkill River were computed by applying rainfall excesses to individual unit hydrographs for three subareas, routing to points downstream and summing these routed hydrographs for the total flow at Philadelphia. The basin project flood on the Brandywine Creek was computed with the storm of 20-24 August 1933 in the same transposed position. Table M-26 gives the peak discharges and volumes at Philadelphia, and Wilmington, Delaware for the basin project flood and also the peak discharges for the maximum flood of record.

136. STANDARD PROJECT FLOOD. In general terms the "standard project flood" is defined as a hydrograph representing runoff from the "standard project storm," and represents a standard against which the degree of flood protection finally selected may be judged and compared with protection provided by similar projects in other localities. The standard project storm estimate represents the most severe flood producing rainfall depth-area-duration relationship and isohyetal pattern of any storm that is considered reasonably characteristic for the region in which the drainage basin is located, giving consideration to the runoff characteristics and existence of water regulation structures in the basin.

137. For basins having areas less than 1,000 square miles the standard project flood estimate was, for the most part, computed in accordance with the generalized procedures discussed in detail in Civil Engineering Bulletin No. 52-8. It was frequently convenient, particularly in the case of reservoir projects, to estimate the standard project flood as equal to 50 percent of the hydrograph resulting from the runoff generated by the probable maximum precipitation. Inasmuch as computation of the flood hydrograph generated by the probable maximum precipitation was required for the determination of spillway requirements, its use in this manner avoided the preparation of a separate standard project flood estimate.

138. In the development of the standard project flood criteria for larger drainage basins, over 1,000 square miles, or those in which reservoirs serve to substantially alter runoff rates, a standard project flood series was developed in accordance with established procedures, in which hydrographs for periods antecedent to and subsequent to a standard project flood were represented by flows actually observed in the basin. In general, the standard project flood series consists of three basic hydrographs; an antecedent flood hydrograph, generally the flood of record, followed, about five days later, by the

standard project flood and this, in turn, is followed by the tailing out of the flood of record. For example, the contributing area above Tocks Island is greater than 1,000 square miles, hence it was necessary to develop the standard project flood series at this site. The flood series is composed of the antecedent flow which is the actual August 1955 flow at Tocks Island followed five days later by the standard project flood hydrograph, based on computed runoff resulting from the rainfall transposition of the 17-19 August 1955 storm, centered near Mt. Pocono, Pennsylvania, and finally the tailing out of the August 1955 flood hydrograph.

139. The generalized standard project storm rainfall criteria presented in Civil Engineering Bulletin No. 52-8 are based on analysis of major storms of record that occurred in the spring, summer, or fall seasons, during which convective activity is prominent. The criteria are not generally applicable to snow seasons without special adjustments. However, rainfall and runoff records indicate that the most severe flooding, in the basin, usually results from intense rainfall during the non-snow season and, accordingly, the generalized storm rainfall criteria was adopted as directly applicable in the determination of the standard project storm rainfall. These criteria and their applications consist of three principal elements which are discussed briefly in the following paragraphs.

a. The rainfall index which represents the maximum average depth of rainfall in 24 hours over 200 square miles during the standard project storm, is estimated, for the area under consideration, using the generalized index rainfall isohyetal map. The isohyets on this chart were prepared by reducing the isohyets of maximum probable precipitation in 24 hours over 200 square miles by 50 percent.

b. A standard elliptical isohyetal pattern which was determined from an average of the patterns for the maximum storms of record is centered over the basin and the maximum rainfall depth is computed.

c. Charts indicating average time distribution of storm rainfall, which were determined from storms of record, are then used to determine the hourly distribution of the standard project rainfall.

140. The standard project flood hydrograph, the flow generated by the standard project storm, was computed using infiltration rates similar to those derived from analyses of the greatest floods of record in the basin. An initial loss of 0.5 inches and an infiltration index of 0.06 inches per hour were adopted as representative of values likely to prevail during the standard project flood. The estimated infiltration losses were subtracted from the standard project storm rainfall to obtain rainfall-excess quantities which were used with unit hydrographs in computing the standard project flood discharges.

141. The standard project flood is intended as a practicable expression of the degree of protection that should be sought as a general rule in the design of flood control works where the protection of human life and unusually high valued property is involved. In this survey, protection against the standard project flood has been considered in the design of all projects incorporating flood control functions. The standard project flood was developed for all projects incorporated in the final plan and pertinent data are shown on table M-27.

TABLE M-27
STANDARD PROJECT FLOODS

Reservoir Site	Drainage Area	Standard Project Flood			
		Flood Volume(1)		Peak Inflow	
	(sq.mi.)	(ac.-ft.)	(in.)	(c.f.s.)	(c.f.s./ sq.mi.)
Prompton (revised)	60	42,500	13.28(2)	19,200	320.0
Tocks Island	3,827	1,094,000	5.36	393,000	102.7
Bear Creek (raised)	288	120,600	7.85(3)	58,000	201.4
Beltzville	97	53,300	10.31	20,500	211.3
Aquashicola	66	37,800	10.73	17,600	266.7
Trexler	51	29,300	10.76	21,000	411.8
Maiden Creek	161	87,200	10.16	49,000	304.3
Blue Marsh	175	77,700	8.32	36,500	208.6

(1) Includes base flow except at Prompton and Bear Creek.
(2) Definite Project Report, April 1949.
(3) Hydrology Supplement to Definite Project Report, Aug 1956.

142. DESIGN FLOODS. For the design of flood control works the standard project flood, the development of which is discussed in paragraphs 136 to 141, was used as the criterion for establishing the upper limit of flood protection to be provided. Additional studies were made to determine the optimum degree of protection that can be provided within the limits of economic justification based on the tangible and intangible benefits derived from the proposed flood control project. The maximum degree of justifiable protection determined in this manner was reviewed critically and where consideration of public safety or other factors warranted greater protection, the degree of protection was modified accordingly. In such cases the degree of protection finally adopted fixed the "design flood" of the projects.

143. Reservoir Design Flood. The reservoir design flood is defined as a flood which the reservoir must accommodate without the water surface rising above the crest of the spillway, assuming that the reservoir is empty (at inactive or water supply pool level) and the flood regulating outlets are operative. With the standard project flood established as the upper limit of hazard development against

which protection would be sought, the degree of protection that would be provided within the limits of the cost justified by the benefits was determined. This was done by routing various percentages of the standard project flood through a limited range of reservoir capacities and determining the downstream effect of reservoir control. The maximum degree of protection that was thus found to be justified, growth factors for the protected areas, present or potential hazards to human life, and other considerations established the basis for determination of the design flood for the project. Pertinent data on the design floods and reservoir flood control capacities for the projects of the comprehensive plan of development are shown in table M-28.

144. Levee Design Flood. In instances where levees, dikes, and floodwalls were considered for a locality and hazard to human life and protection of highly valuable property are involved, a high degree of protection was assumed warranted. In planning for projects in this class the design flood was selected as equal to or closely approaching the standard project flood, but in no case was it less than the maximum flood of record. In agricultural or sparsely populated rural areas a relatively lower degree of protection by means of levees was investigated in arriving at the design flood magnitude. However, consideration was given to the possibility that this limited protection may provide a false sense of security and aggravation of the flood problem. Where such conditions might prevail the degree of protection under consideration was increased to avoid these adverse effects.

145. Channel Design Flood. The design flood for channel improvement works under consideration was based on the economic degree of reduction of flood stages obtainable through increase in channel capacity. In recommendations for the final comprehensive plan of development, channel improvement works were not considered where they afforded such a low degree of protection that, even though theoretically justifiable, they would create a false sense of security and lead to more serious flood problems by encouraging further development within the flood plain.

146. SPILLWAY DESIGN CAPACITIES. The term "spillway design flood (SDF)" is defined as the hydrograph finally selected as a basis for estimating spillway design capacities required in conjunction with various storage capacities (heights of dams), spillway surcharges and ranges of freeboard. For dam structures in this report the probable maximum flood hydrograph was used for determining spillway capacities.

147. Spillway Design Storm. General storm phenomena and probable maximum precipitation for the spillway design storm were furnished by the Hydrometeorological Section of the U. S. Weather Bureau by various memoranda as follows:

TABLE M 28

RESERVOIR DESIGN FLOODS FOR ESTABLISHING FLOOD STORAGE REQUIREMENTS

Reservoir	Drainage Area	Allocated Flood Control Storage	Reservoir Design Flood (1) Peak Inflow	Flood Volume		Peak Outflow	Ratio 69 SPF
	(sq. mi.)	(ac-ft.)	(cfs)	(ac-ft.)	(inches)	(cfs)	(%)
Prompton (revised)	60	20,300	13,300(2)	29,500	9.20	3,000	69.3
Tocks Island (3)	3,827	275,000	210,600	586,400	2.87	70,000	53.6
Bear Creek (raised)	288	108,000	standard project flood completely controlled (4)				
Beltzville	97	27,000	14,600	37,900	7.32	1,500	71.0
Aquashicola	66	20,000	13,600	29,100	8.26	1,500	77.0
Trexler	51	14,000	15,000	20,900	7.67	1,500	71.3
Maiden Creek	161	38,000	29,800	53,000	6.18	2,500	60.8
Blue Marsh	175	33,000	22,400	47,800	5.12	2,500	61.5

(1) Operation during reservoir design flood - Outflow is equal to inflow until outflow reaches zero damaging discharge, then outflow is held constant at this discharge.
(2) Definite Project Report, April 1949.
(3) Outflow discharge 35,000 cfs until 6 hours past the peak, then 70,000 cfs.
(4) Hydrology Supplement to Definite Project Report, August 1956

"Preliminary Estimate of Probable Maximum Precipitation for the Lackawaxen and Middle Creek Basins above Hawley, Pennsylvania," dated 27 April 1956.

"Preliminary Estimate of Probable Maximum Precipitation for Brodhead Creek and McMichaels Creek of the Delaware River Basin," dated 18 June 1956.

"Preliminary estimate of Probable Maximum Precipitation for the Delaware River at Tocks Island Dam Site," dated 3 July 1956.

"Preliminary Estimate of Probable Maximum Precipitation for the Delaware River Basin above Barryville Dam Site, New York," dated 30 July 1956.

"Preliminary Estimate of Probable Maximum Precipitation for Neversink Basin above Godeffroy Dam Site, New York," dated 23 August 1956.

"Preliminary Estimate of Probable Maximum Precipitation, Wallenpaupack Creek above Newfoundland, Pennsylvania," dated 28 August 1956.

"Preliminary Estimate of Probable Maximum Precipitation for Delaware River above Trenton, New Jersey (5,000 to 7,000 sq. mi.); above Chestnut Hill Dam Site (4,625 sq. miles); and above Belvidere Dam Site (4,365 sq. miles)," dated 19 November 1956.

"Estimate of Probable Maximum Precipitation for: Brandywine Creek above Coatesville, Pennsylvania; Neshaminy Creek above Bridge Valley, Pennsylvania; Pohopoco Creek above Parryville, Pennsylvania; Aquashicola Creek above Palmerton, Pennsylvania; and Perkiomen Creek above Sumneytown, Pennsylvania," dated 12 February 1957.

"Preliminary Estimate of Probable Maximum Precipitation for the East Branch of the Delaware above Hancock Dam Site," dated 18 February 1957.

"Preliminary Estimate of Probable Maximum Precipitation for Neversink River above Denton Dam Site (191 sq. miles)," dated 18 February 1957."

Rainfall was assumed to be uniformly distributed over the watershed. Estimates of the depth-duration values of maximum possible precipitation as given in the aforementioned data from the U. S. Weather Bureau were arranged by 6-hour increments of rainfall in a typical storm pattern with the greatest increment near the midpoint. An initial loss of 0.5 inch and subsequent losses of 0.05 inch per hour were representative of values assumed to prevail during the spillway design

flood. These loss rates were compared with those shown on plate 5, Engineering Manual, EM 1110-2-1405, and are considered conservative.

148. Spillway Design Flood. To determine the reservoir inflow hydrographs for the spillway design flood, the spillway design storm runoff was applied to the inflow unit hydrographs at the various dam sites. Runoff from the areas adjacent to the reservoirs plus 100 percent runoff for the area covered by the full reservoir was added to the inflow. Pertinent data on spillway design floods and spillway designs for all projects included as elements in the final comprehensive plan are tabulated in table M-29.

149. Spillway Length-Discharge Relations. In estimating spillway requirements for reservoirs the spillway design flood, discussed in paragraph 148, was routed through reservoir storage assuming various spillway crest lengths with the low-level outlets operative. It was assumed that when the spillway design flood arrived the reservoir would be full and the water surface would be at the spillway crest. Under such assumptions the reservoir could pass an infinite succession of spillway design floods at reasonably close intervals with perfect safety to the dam structure. Based on the above assumption and on several assumed spillway crest lengths the spillway design flood was routed through reservoir storage for each crest length utilizing the routing methods discussed in paragraph 119. Plate 72 shows a sample plot of maximum reservoir stage and spillway outflow resulting from the routing of the spillway design flood through the reservoir with various assumed spillway crest lengths. These data were correlated with economic appraisals of various spillway systems considered and used to assist in selecting the most satisfactory spillway for the project.

150. Freeboard Requirements. Freeboard requirements for reservoir projects are based on recent estimates of wind criteria, wave height, and runup values developed in connection with a study of freeboard requirements for the McGee Bend Dam, Texas.20/ General criteria established for that project are as follows:

a. Effective fetch was determined by drawing seven radial fetch lines at intervals of six degrees on each side of the maximum fetch. The projection of each radial on the maximum fetch was multiplied by the cosine of the angle between the radial and the maximum fetch and summated. The effective fetch resulted upon dividing this total by the sum of the cosines of the angles.

20/ "Conference on Determination of Freeboard Requirements for the McGee Bend Dam, Angelina River, Texas," dated 1 August 1956.

TABLE M 29

REQUIRED SPILLWAY CAPACITIES

Project	Drainage Area	ELEVATIONS In-active Pool	Spill-way Crest	Top of Dam	SPILLWAY DESIGN FLOOD INFLOW Peak	Volume (1)	SPILLWAY Crest Length	Maximum Discharge	Sur-charge
	(sq.mi.)	(feet above M.S.L.)			(cfs)	(ac-ft.)	(ft.)	(cfs)	(ft.)
Hawk Mountain	812	1,008	1,082	1,109	202,000	550,600	550	168,000	20.2
Prompton(revised)	60	1,125	1,205	1,226	81,500(2)	75,500	250	61,000	17.0
Tocks Island	3,827	356	395(3)	456	785,000	2,332,200	472(4)	600,000	51.7
Bear Creek(raised)	288	1,300	1,481	1,503	170,000(5)	309,000	500	128,500	16.6(6)
Beltzville	97	525	641	658	48,500	114,600	400	41,000	10.4
Aquashicola	66	435	503	523	42,500	85,300	160	30,700	13.6
Trexler	51	416	492	508	50,000	69,600	200	31,000	13.4
Maiden Creek	161	323	394	412	118,000	202,000	750	92,000	11.3
Blue Marsh	175	249	303	320	117,000	215,000	900	113,000	11.4
Newark	67	98	156	172	103,000	93,200	400	93,500	14.8
Christiana	41	23	49	62	39,200	61,900	250	17,000	7.5

(1) Includes base flow
(2) Definite project report, April 1949
(3) Gates - el. 395 to 428
(4) 10 Bays, 40' each
(5) Revised spillway design flood, June 1956
(6) Assuming 50% of gated outlet capacity available

b. The depth of the water in the reservoir was measured from the normal operating pool to the deepest point in the reservoir. Accordingly wave estimates presented correspond to deepwater waves since reservoir depths exceed 1/3 to 1/2 the wavelength.

c. The significant wave height was determined from average relationships between wind velocities, effective fetches and reservoir depths. These expirical relations are based on experimental data developed in connection with Civil Works Investigations 164 and 165, and are shown in reference 20/.

d. Wave runup, which is produced as the wave breaks on the embankment, is dependent on the slope and the porosity of the embankment, the size of the riprap, and the wave characteristics. Generalized relationships for estimating wave runup were developed by the Beach Erosion Board and presented in an informal memorandum by Mr. Thorndike Saville, Jr., dated 27 July 1956.

e. Wind setup refers to the rise in water surface at a particular point produced by frictional effects of a persistent wind. Estimates of wind setup are based on the Zeider Zee formula.

151. A study of wind records in the Delaware basin indicates that maximum wind velocities were experienced during hurricane occurrences. However, from a consideration of probable reservoir operating plans and pool level frequencies it was assumed that critical hurricane winds might be expected to coincide with a lower reservoir level which would be reached approximately once every 10 years. The occurrence of extreme sustained hurricane winds simultaneously with the spillway design flood and accompanying maximum reservoir stage is of such extreme infrequency as to be safely disregarded. Accordingly, freeboard requirements for the reservoir projects within the Delaware basin are based on a maximum wind velocity of 40 miles per hour coincident with the maximum reservoir level attained during the spillway design flood. A generalized relationship was developed from the aforementioned data and used for determining freeboard estimates for all projects included as elements in the final plan and are shown on table M-30.

152. OUTLET DESIGN CAPACITIES. Outlet capacities for release of water supply must be adequate to make, under all conditions, the releases necessary to meet the water demands downstream. For planning purposes these capacities were determined from an analysis of basin yields to assure flexible and full control of these yields up to the maximum water demand required at downstream reaches. In outlets for multipurpose projects, where releases for water supply and flood control are combined in a common conduit through the dam, maximum design capacities are generally based on flood control requirements as these flows would be considerably larger than the maximum releases required for water supply.

TABLE M 30

FREEBOARD REQUIREMENTS

For Wave Run-up Plus Wind Set-up
(Exclusive of Requirement for Frost Action)

Project	Drainage Area (sq.mi.)	Effective Fetch (mi.)	Reservoir Depth (1) (ft.)	Freeboard Requirement (ft.)
Hawk Mountain	812	2.0	152	3.9
Prompton(revised)	60	0.4	94	1.7
Tocks Island	3,827	6.0	110	6.4
Bear Creek(raised)	288	1.0	185	2.8
Beltzville	97	2.0	120	3.9
Aquashicola	66	2.5	63	4.3
Trexler	51	0.6	89	2.1
Maiden	161	2.5	71	4.3
Blue Marsh	175	2.0	44	3.9
Newark	667	0.2	80	1.2
Christiana	41	1.5	41	3.4

(1) Measured from river bed to lower limit of flood control storage.

153. <u>Factors governing size of outlets</u>. The fundamental factors to be considered in the selection of outlet capacities for flood control projects are the required diversion flow during construction, the downstream channel capacity, the time required to evacuate the flood storage, and the combined use of the uncontrolled outlet capacity and the reservoir storage to effectively control a range of flood flows in the vicinity of the site.

154. <u>Criteria</u>. For planning purposes the determination of the outlet capacities of the reservoirs was based on the following criteria:

a. In cases where the outlet will also serve as the diversion tunnel during construction of the dam, the diversion capacity will be adequate to pass safely a flood having a recurrence interval of once in approximately eight years assuming a cofferdam of reasonable height as temporary closure during construction operations at the dam site.

b. With the reservoir surface at a level corresponding to 20 percent of the flood control storage, the outlet works should be capable of discharging at a rate which is at least equal to the non-damaging downstream channel capacity. This latter capacity will be determined from an examination of critical key points downstream from the various projects. The discharge capacities at which appreciable and major flood damage begins will be based on available stage-damage data, field investigations and, if necessary, by backwater studies.

c. The capacity of the outlet works shall be such that it will permit evacuation of the flood control storage in not more than 10 days. The design of gated outlet works should be such that discharge for dewatering of a full reservoir to conservation pool level can be accomplished with full gate openings.

155. <u>INACTIVE STORAGE CAPACITY</u>. Reservoir capacity allocated as inactive storage normally consists mainly of the volume reserved for sediment accumulation over the life of the project. It should be recognized that a portion of the sediment load will be deposited outside the limits of the inactive pool but still within the overall physical limits of the reservoir. Existing sediment data for the Delaware River basin treats only with suspended sediments, although observation indicates that a much greater problem exists in the movement of bed material into the main stem of Delaware River from the tributaries. The U. S. Geological Survey has performed statistical analyses of the suspended sediment loads for a given runoff on streams in the Delaware River basin. These analyses show that for Delaware River at Trenton there was no significant trend toward increasing or decreasing sediment loads during the period from October 1949 to February 1956. Also, that for Schuylkill River at Manayunk in Philadelphia, for the period

November 1947 to September 1954, and for Lehigh River at Walnutport, Pennsylvania, for the period June 1947 to March 1953, there were definite trends toward decreasing suspended sediment loads for a given runoff at both stations.

156. Due to the paucity of data on total sediment, both suspended and bedload, the allowance for sediment storage in reservoirs was made on the basis of available sediment data from adjacent watersheds and reservoir sedimentation data available from the Subcommittee on Sedimentation, Federal Inter-agency River Basin Committee.21/ Utilizing data from seven reservoirs in or adjacent to the Delaware River basin, an average value of 0.119 acre-feet per square mile of annual sediment accumulation was determined. In arriving at the inactive storage capacity for each project an amount required for sediment storage was first computed on the basis of this average value. Also, it was noted that inactive pools are invariably used locally for recreation purposes even in the absence of specific public use development at the project. In recognization of this, the pool required for sediment storage only was reappraised on the basis of its use for recreation and the final inactive storage proposed for each site was adjusted by judgment to permit reasonable use of the pool for that purpose. In most cases the area of the inactive pool was set to provide a minimum commensurate with potential public uses. Furthermore, as the reallocation of the inactive storage capacity progresses commensurate with the accumulation of sediment, it is considered prudent to reserve at all times some storage capacity that will be available for releases for fish and wildlife purposes during the possible occurrence of an extreme prolonged drought. These adjustments resulted in an inactive storage capacity greater than that required solely for sediment accumulation. In addition, inactive storage has been increased in order to limit drawdown at the sites where generation of hydroelectric power is a project purpose. Consequently, the inactive storage allocations at Tocks Island and Hawk Mountain are considerably larger than would otherwise be required.

21/ Summary of Reservoir Sedimentation Surveys for the United States through 1955, April 1957, Sedimentation Bulletin No. 6.

SECTION VII - EFFECTS OF PROPOSED WATER CONTROL PLAN

157. RESERVOIR REGULATION SCHEDULES. The reservoir regulation schedules for the various projects in the Water Control Plan are given in general terms for the operation of short term storage for flood control and the operation of long term storage for water supply and other uses. The general description and pertinent data for each project are given in Appendix U. All projects except Tocks Island have uncontrolled spillways and controlled low level outlets with gate tower and trash racks. Tocks Island project has a controlled spillway with ten tainter gates, individually operated, and a controlled low level outlet with gate tower and trash racks. The storage allocations for the individual projects are given in table M-31. Plate 79 shows the locations of the projects and also the reference points used in defining the impoundment effects. The general plan of operation for short and long term storages in all projects is given in the following paragraphs.

158. Short Term Storage. Operation of short term storage for flood control of all projects will be primarily in the interest of local flood reductions to the safe discharge capacity of the channel, insofar as practicable, as well as for more general flood control in the downstream reaches of the lower Delaware River. During the storage period, reservoir outflow for all projects will be regulated generally in accordance with the following criteria:

a. When the pool level is between the top of inactive and top of active long term storage, outflow will be released according to normal requirements for water supply and other uses.

b. When the pool level is above the top elevation of the active long term storage, releases will be so regulated that outflows combined with local inflow to the reaches below the dam will not exceed the safe discharge capacity of the channel. After the storage period reservoir outflow will be regulated so as to evacuate the short term storage from the reservoir by maintaining conditions given above in order to empty that portion of the reservoir above the top of active long term storage as rapidly as possible without increasing or prolonging serious flooding in reaches downstream from the dam.

159. Long Term Storage. Operation of long term storage mainly for water supply needs downstream will be based on the scheduled demands at designated reference points. The three reference points in the basin were considered as Lehigh River at Bethlehem, Schuylkill River at Pottstown, and Delaware River below Philadelphia. The last reference location was considered for the combined flows of Delaware and Schuylkill Rivers at Trenton and Philadelphia, respectively, and is referred to hereafter as the Trenton-Philadelphia reach. Reservoir releases from projects on Lehigh and Schuylkill Rivers will be such as

TABLE M-31
STORAGE ALLOCATIONS IN WATER CONTROL PROJECTS

Project	Long Term: Inactive: Elevation Limits (ft. above m.s.l.)	Long Term: Inactive: Capacity (ac.-ft.)	Long Term: Active: Elevation Limits (ft. above m.s.l.	Long Term: Active: Capacity (ac.-ft.)	Short Term: Elevation Limits (ft. above m.s.l.)	Short Term: Capacity (ac.-ft.)
Major Impounding Structures						
Hawk Mountain	Riverbed to 1,008.0	60,000	1,008.0 to 1,082.0	233,000	-	-
Prompton (revised)	Riverbed to 1,125.0	3,400	1,125.0 to 1,180.0	28,000	1,180.0 to 1,205.0	20,300
Tocks Island	Riverbed to 356.0	80,000	356.0 to 410.0	410,000	410.0 to 428.0	275,000
Bear Creek (raised)	Riverbed to 1,300.0	2,000	1,300.0 to 1,425.0	70,000	1,425.0 to 1,481.0	108,000
Beltzville	Riverbed to 525.0	1,200	525.0 to 615.0	40,000	615.0 to 641.0	27,000
Aquashicola	Riverbed to 435.0	1,000	435.0 to 483.0	24,000	483.0 to 503.0	20,000
Trexler	Riverbed to 416.0	800	416.0 to 479.0	24,200	479.0 to 492.0	14,000
Maiden Creek	Riverbed to 323.0	2,000	323.0 to 381.0	74,000	381.0 to 394.0	38,000
Blue Marsh	Riverbed to 249.0	1,500	249.0 to 279.0	14,500	279.0 to 303.0	33,000
Newark	Riverbed to 98.0	1,000	98.0 to 156.0	30,000	-	-
Christiana	Riverbed to 23.0	1,000	23.0 to 49.0	36,000	-	-
Intermediate Upstream Impounding Structures 1/						
Parkside	Riverbed to 768.0	52	-	-	768.0 to 822.0	2,218
Swiftwater	Riverbed to 888.0	71	-	-	888.0 to 942.0	3,279
Jim Thorpe	Riverbed to 952.5	84	-	-	952.5 to 976.0	1,450

1/ Projects which cannot be constructed under existing small dam programs without further authorization.

to satisfy local demands at Bethlehem and Pottstown, respectively, as well as the demands in the Trenton-Philadelphia reach. All reservoirs in the system will be required to provide their proportionate share of the Trenton-Philadelphia demand. However, in such cases where the local demands are higher than the proportionate share of the Trenton-Philadelphia flow requirement, the local demand will be used as the release criterion to assure adequate provision for local needs. This method of operation will assure the maintenance of flows to satisfy demands at all reference points, although at times provisions for the Trenton-Philadelphia needs may provide higher flows in the local areas than needed and, conversely, flows in the Trenton-Philadelphia area may be greater than the demand when local water supply needs govern. When unregulated flows at reference points are sufficiently high to impose no demands on the reservoir system, conservation releases will be made for the preservation of fish and wildlife and the maintenance of acceptable minimum levels of streamflow immediately below project sites. These conservation releases will be based on maintaining the 95 percent minimum flows of the various project streams as given in table M-24 of this appendix, except for the Tocks Island project. The required minimum flow below Tocks Island dam, as modified by New York City's reservoir system, operating in accordance with the Supreme Court Decree of 1954, will be about 1,800 c.f.s.

160. EFFECTS OF WATER CONTROL PLAN ON FLOODS. The effects of the short-term storage allocation in reservoirs of the Water Control Plan were computed for the Basin Project Flood and the two record floods of 23-24 May 1942 and 18-19 August 1955. Operation of the reservoirs during these floods was in accordance with general regulation schedules outlined in paragraph 158. The effects of the entire reservoir system on peak discharges and stages at various points throughout the basin are given in table M-32. Actual flood hydrographs and hydrographs modified by the effects of existing storage and storage proposed in the Water Control Plan are shown in plates 73 to 75 inclusive.

161. EFFECTS OF WATER CONTROL PLAN ON LOW FLOWS OF A MAJOR DROUGHT PERIOD. In order to demonstrate the effects of long-term storage allocations in reservoirs of the Water Control Plan on low flows the system was operated during the three-year drought period 1930, 1931 and 1932 with operating criteria based on water demands for specific target years throughout the course of system development. These target years were selected as 1988, just prior to raising of Bear Creek dam and reservoir, and 2010, which is the end of the projection period. The projects proposed in the system by 1988 are Beltzville, Trexler and Aquashicola in the Lehigh River basin, Blue Marsh and Maiden in the Schuylkill River basin, Prompton (revised) on Lackawaxen River, and Tocks Island on Delaware River. The system in 2010 would include all of these projects plus Bear Creek (raised) in the Lehigh River basin and Hawk Mountain on East Branch Delaware River.

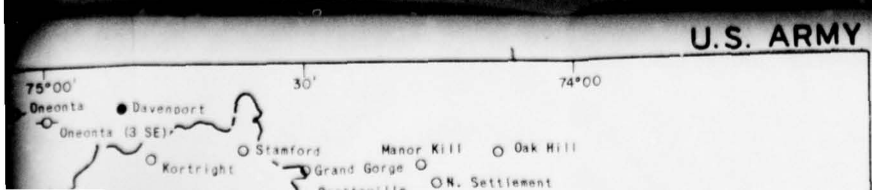

TABLE M-32

FLOOD CONTROL EFFECTS OF THE RESERVOIR SYSTEM

	Actual		Regulated by E & U Reservoirs 1/		Regulated by Water Control Plan	
	Discharge c.f.s.	Stage 2/ ft.	Discharge c.f.s.	Stage 2/ ft.	Discharge c.f.s.	Stage 2/ ft.
Flood of May 1942						
Delaware River at Belvidere, N. J.	133,700	21.2	119,000	20.0	43,000	12.1
Lehigh River at Bethlehem, Pa.	92,000	23.5	72,100	19.9	63,500	18.3
Delaware River at Riegelsville, N.J.	164,000	26.7	144,000	24.9	85,000	18.4
Delaware River at Trenton, N. J.	161,200	13.4	140,000	12.3	80,000	8.6
Schuylkill River at Reading, Pa.	43,000	20.6	43,000	20.6	27,400	15.9
Schuylkill River at Pottstown, Pa.	50,800	20.2	50,800	20.2	40,500	17.5
Schuylkill River at Philadelphia, Pa.	61,900	12.4	61,900	12.4	48,800	11.4
Flood of August 1955						
Delaware River at Belvidere, N. J.	273,000	30.21	275,000	30.3	121,000	20.2
Lehigh River at Bethlehem, Pa.	91,300	23.38	83,000	21.9	72,000	19.9
Delaware River at Riegelsville, N.J.	340,000	38.85	304,000	36.7	164,000	26.6
Delaware River at Trenton, N. J.	329,000	20.83	295,500	19.5	162,000	13.5
Schuylkill River at Reading, Pa.	33,300	18.06	33,300	18.06	21,200	13.7
Schuylkill River at Pottstown, Pa.	42,300	17.98	42,300	17.98	31,300	15.0
Schuylkill River at Philadelphia, Pa.	90,100	14.32	90,100	14.32	88,000	14.2
Basin Project Flood	Natural					
Delaware River at Belvidere, N. J.	321,000	33.0	283,500	30.9	127,500	20.7
Lehigh River at Bethlehem, Pa.	133,900	30.1	104,200	25.4	81,700	21.6
Delaware River at Riegelsville, N.J.	423,800	43.1	368,000	40.1	166,000	26.8
Delaware River at Trenton, N. J.	417,200	23.9	358,000	21.9	167,000	13.7
Schuylkill River at Reading, Pa.	88,500	28.0	88,500	28.0	52,600	22.8
Schuylkill River at Pottstown, Pa.	109,000	32.0	109,000	32.0	74,500	25.5
Schuylkill River at Philadelphia, Pa.	191,000	19.7	191,000	19.7	180,000	19.1

1/ Existing reservoirs and projects under construction.

2/ Based on 1955 stage-discharge rating information.

Operation of the reservoirs during the three-year drought flows centered at the two target years was in accordance with general regulation schedules outlined in paragraph 159. Data for the system operation consisted of mean monthly flows for the various streams at each project in the system during the three-year period January 1930 through December 1932. The water demands at the reference points for the target years 1988 and 2010 are as follows:

Stream and Reference Point	Demand Flow - c.f.s. 1988	2010
Lehigh River at Bethlehem	510	740
Schuylkill River at Pottstown	400	510
Delaware River at Trenton	3,650	4,720
Trenton-Philadelphia Reach	4,080	5,860

The projected demand for the Trenton-Philadelphia area in the year 2010 as given in Appendix P is 5,290 c.f.s. However, the demand of 5,860 c.f.s. was adopted for this operation in order to provide as high a sustained minimum flow as possible by fully utilizing the total storage capacity of the system. The 570 c.f.s. excess flow, which is provided, may be drawn upon when needed for diversions to the Wilmington, Delaware area and the area of northern New Jersey. The observed and modified flows for the target years of 1988 and 2010 are shown in tables M-33 and M-34 and on plates 76 and 77.

162. In general it may be concluded that the proposed system of impoundments is adequate to provide water supplies for the Delaware River basin as projected to the year 2010. It must be emphasized, however, that the projected demands are average demands and subject to considerable variation not only from year to year but within years as well. It must also be recognized that the method of operation adopted for use in this study, while adequate for monthly flows, will not necessarily apply to daily operation schedules closely related to fluctuating demands and priorities of other uses, such as flood control, power, and recreation.

163. FREQUENCIES OF RESERVOIR POOL LEVELS. Five-year frequency water surface elevations were estimated for each major impounding project in the water control plan. The five-year inflow volumes, based on generalized maximum volume-duration frequency studies, were routed through the reservoirs using normal releases through the outlets to obtain the maximum pool elevations for each project. Pertinent data and resulting pool elevations are given in table M-35. A separate study was made for the Tocks Island Project to show pool levels versus frequency. A 24-year array of annual peak flood volumes of inflow to the reservoir was constructed from all available pertinent records of gaging stations on streams tributary to the reservoir for the period 1924-1932. From this array reservoir volumes were

TABLE M-33

EFFECTS OF PLAN OF IMPROVEMENT ON LOW FLOWS DURING DROUGHT OF 1930-1932 WITH PROJECTED WATER DEMANDS OF YEAR 1988

	Lehigh River at Bethlehem		Delaware River at Trenton		Schuylkill River at Pottstown		Schuylkill River at Philadelphia		Del. R. at Trenton + Sch. R. at Phila.	
	Reference Flow	Modified Flow	Reference Flow	Modified Flow	Reference Flow	Modified Flow	Reference Flow	Modified Flow	Reference Flow	Modified Flow
1930	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
January	2,270	2,270	10,490	10,490	1.730	1,730	2,650	2,650	13,140	13,140
February	2,060	2,060	10,420	10,420	2,160	2,160	3,870	3,870	14,290	14,290
March	3,110	3,110	16,270	16,270	2,520	2,520	3,740	3,740	20,010	20,010
April	3,290	3,290	13,070	13,070	2,330	2,330	3,180	3,180	16,250	16,250
May	2,280	2,280	6,640	6,640	1,300	1,300	1,870	1,870	8,510	8,510
June	2,010	2,010	7,680	7,680	950	950	1,300	1,300	8,980	8,980
July	1,120	1,160	3,950	3,990	460	510	650	700	4,600	4,690
August	560	860	2,700	3,650	310	550	410	640	3,110	4,290
September	520	790	2,690	3,650	350	570	440	650	3.130	4,300
October	400	660	2,540	3,650	260	490	300	530	2,840	4,180
November	420	590	2,910	3,650	310	470	410	560	3,320	4,210
December	470	580	3,040	3.650	420	520	590	690	3,630	4,340
1931										
January	690	670	4,160	3,960	690	630	1,060	1,000	5,220	4,960
February	1,080	1,030	4,810	4,430	950	830	1,550	1,420	6,360	5,850
March	2,100	1,720	10,710	7,560	1,360	970	2,010	1,620	12,720	9,180
April	2,770	2,250	16,160	15,640	1,510	1,100	2,180	1,770	18,340	17,410
May	2,760	2,600	13,040	12,880	1,800	1,780	2,430	2,420	15,470	15,300
June	1,410	1,410	8,100	8,100	1,100	1,100	1,790	1,790	9,890	9.890
July	1,490	1,490	8,950	8,950	1,370	1,370	2,790	2,790	11,740	11,740
August	840	870	3,700	3,740	740	740	1,290	1,290	4,990	5,030
September	700	880	3,130	3,650	550	690	880	1,020	4,010	4,670
October	460	740	2,550	3,650	400	640	600	840	3,150	4,490
November	410	670	2,460	3,650	310	560	440	700	2,900	4,350
December	620	750	3,650	3,650	530	650	740	860	4,390	4,510
1932										
January	1,630	1,380	9,840	7,630	1,900	1,620	3,030	2,750	12,870	10,380
February	1,710	1,480	10,640	10,420	1,210	960	1,700	1,460	12,340	11,880
March	2,110	1,820	8,540	8,240	2,290	2,070	3,620	3,400	12,160	11,640
April	3,440	3,310	18,780	18,650	2,500	2,500	3,790	3,790	22,570	22,440
May	1,920	1,920	8,540	8,540	1,880	1,880	2,560	2,560	11,100	11,100
June	1,420	1,420	6,040	6,040	1,060	1,060	1,360	1,360	7,400	7,400
July	910	1,030	3,760	3,890	560	640	730	810	4,490	4,700
August	550	810	2,680	3,650	440	650	580	790	3,260	4,440
September	370	660	2,440	3,650	260	520	350	620	2,790	4,270
October	1,420	1,190	7,710	5,860	1,260	990	1,750	1,480	9,460	7,340
November	4,950	4,500	22,640	22,190	3,760	3,470	6,420	6,130	29,060	28,320
December	1,710	1,710	7,880	7,880	1,530	1,530	2,380	2,380	10,260	10,260

Reference flows in columns (1), (5), and (7) are observed mean monthly flows.

Columns (3) and (9) are modified for the effects of a projected operation of Pepacton, Neversink and Cannonsville with diversion of 800 mgd to NYC and maintenance of 1750 cfs at Montague, NJ, in accordance with provisions of the Supreme Court Decree of 1954.

Columns (2), (4), (6), (8) and (10) are modified flows resulting from operation of the proposed system of impoundments. See Plates 76 and 77.

TABLE M-34

EFFECTS OF PLAN OF IMPROVEMENT ON LOW FLOWS DURING DROUGHT OF 1930-1932 WITH PROJECTED WATER DEMANDS OF YEAR 2010

	Lehigh River at Bethlehem		Delaware River at Trenton		Schuylkill River at Pottstown		Schuylkill River at Philadelphia		Del. R. at Trenton + Sch. R. at Phila.	
	Reference Flow	Modified Flow	Reference Flow	Modified Flow	Reference Flow	Modified Flow	Reference Flow	Modified Flow	Reference Flow	Modified Flow
1930	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
January	2,270	2,270	10,490	10,490	1,730	1,730	2,650	2,650	13,140	13,140
February	2,060	2,060	10,420	10,420	2,160	2,160	3,870	3,870	14,290	14,290
March	3,110	3,110	16,270	16,270	2,520	2,520	3,740	3,740	20,010	20,010
April	3,290	3,290	13,070	13,070	2,330	2,330	3,180	3,180	16,250	16,250
May	2,280	2,280	6,640	6,640	1,300	1,300	1,870	1,870	8,510	8,510
June	2,010	2,010	7,680	7,680	950	950	1,300	1,300	8,980	8,980
July	1,120	1,290	3,950	5,040	460	630	650	820	4,600	5,860
August	560	1,190	2,700	5,170	310	600	410	690	3,110	5,860
September	520	1,090	2,690	5,150	350	620	440	710	3,130	5,860
October	400	950	2,540	5,280	260	550	300	580	2,840	5,860
November	420	810	2,910	5,230	310	540	410	630	3.320	5,860
December	470	740	3,040	5,120	420	590	590	760	3,630	5,880
1931										
January	690	740	4,160	4,760	690	730	1,060	1,100	5,220	5,860
February	1,080	1,030	4,810	4,720	950	910	1,550	1,510	6,360	6,230
March	2,100	1,260	10,710	4,720	1,360	1,000	2,010	1,650	12,720	6,370
April	2,770	1,450	16,160	8,900	1,510	1,100	2,180	1,770	18,340	10,670
May	2,760	2,350	13,040	12,630	1,800	1,200	2,430	1,830	15,470	14,460
June	1,410	1,410	8,100	8,100	1,100	1,040	1,790	1,730	9,890	9,830
July	1,490	1,490	8,950	8.950	1,370	1,370	2,790	2,790	11,740	11,740
August	840	1,060	3.700	4,720	740	860	1,290	1,410	4.990	6.130
September	700	1,130	3,130	4,760	550	780	880	1,100	4,010	5,860
October	460	1,040	2,550	4,980	400	680	600	880	3,150	5,860
November	410	940	2,460	5,130	310	600	440	730	2,900	5,860
December	620	910	3.650	4,940	530	710	740	920	4,390	5,860
1932										
January	1.630	980	9,840	4,720	1,900	1,620	3,030	2,750	12,870	7,470
February	1,710	1,140	10,640	7,560	1,210	960	1,700	1,460	12,340	9,020
March	2,110	1,370	8,540	7,790	2,290	1,830	3,620	3,160	12,160	10,950
April	3,440	3,340	18,780	18,680	2,500	2,390	3.790	3,680	22,570	22.360
May	1,920	1,920	8,540	8,540	1,880	1,880	2,560	2,560	11,100	11,100
June	1,420	1,420	6,040	6,040	1,060	1,090	1,360	1,390	7,400	7,430
July	910	1,210	3,760	4,960	560	730	730	900	4,490	5,860
August	550	1,100	2,680	5,010	440	710	580	850	3,260	5,860
September	370	980	2,440	5,200	260	560	350	660	2,790	5,860
October	1,420	1,000	7,710	4,720	1,260	1,060	1,750	1,550	9,460	6,270
November	4,950	3,910	22,640	19,320	3.760	3.180	6,420	5,840	29,060	25,160
December	1,710	1,710	7,880	7,880	1,530	1,530	2,380	2,380	10,260	10,260

Reference flows in columns (1), (5), and (7) are observed mean monthly flows.

Columns (3) and (9) are modified for the effects of a projected operation of Pepacton, Neversink and Cannonsville with diversion of 800 mgd to NYC and maintenance of 1750 cfs at Montague, NJ, in accordance with provisions of the Supreme Court Decree of 1954.

Columns (2), (4), (6), (8) and (10) are modified flows resulting from operation of the proposed system of impoundments. See Plates 76 and 77.

TABLE M-35
FIVE-YEAR FLOOD VOLUMES AND POOL ELEVATIONS

Project	Drainage Area (sq.mi.)	Top Long Term Pool Elev. (m.s.l.)	Top Long Term Pool Storage (ac.-ft.)	Spillway Crest Elevation (m.s.l.)	5-Year Flood Volume Gross Inflow (ac.-ft.)	5-Year Flood Volume Net Storage (ac.-ft.)	Top 5-Year Flood Pool Storage (ac.-ft.)	Top 5-Year Flood Pool Elev. (m.s.l.)
Hawk Mountain	812	1,082	293,000	1,082	151,000	31,000 1/	324,000	1,087.5
Prompton (rev.)	60	1,180	31,400	1,205	-	2,000 2/	33,400	1,182.5
Bear Cr. (raised)	288	1,425	72,000	1,481	-	38,000 2/	110,000	1,450.0
Beltzville	97	615	41,200	641	12,400	9,400	50,600	625.0
Aquashicola	66	483	25,000	503	7,800	6,000	31,000	490.0
Trexler	51	479	25,000	492	5,800	4,000	29,000	482.5
Maiden Creek	161	381	76,000	394	22,000	16,000	92,000	386.0
Blue Marsh	175	279	16,000	303	24,000	18,000	34,000	294.0
Newark	67	156	31,000	156	8,000	2,000 1/	33,000	157.4
Christiana	41	49	37,000	49	4,400	1,800 1/	38,800	49.6

1/ Surcharge storage.
2/ Based on data from prior studies.

computed for both maximum and minimum conditions of long term storage prior to the flood. Pool elevations so obtained for each year in the volume array were plotted against the associated frequency secured from a log-normal analysis of the annual peak flood volumes. These Tocks Island elevation-frequency curves are presented in plate 78 which shows maximum stages resulting from reservoir regulation of minor and major floods for maximum and minimum conditions of long term storage.

164. DRAWDOWN DURING RECREATION SEASON. It was recognized that drawdown might have an adverse effect on the recreational use of the proposed reservoirs. In order to derive drawdown - frequency relationships, analyses were made of data pertaining to seven representative reservoirs, in different parts of the basin, from among those in the proposed plan. The projects considered in this analysis were Hawk Mountain, Tocks Island, Aquashicola, Beltzville, Trexler, Maiden Creek and Newark. The estimated average monthly inflows applicable to each project site and the assumed constant outflow for each reservoir were combined for the entire period of record to derive corresponding pool elevations for each month. The corresponding drawdowns, in feet, below the normal long-term storage pool level were also derived. The drawdown values for the months of the recreation season, June, July and August, were then tabulated and the frequency of occurrence of the various drawdowns derived. Similar data were also derived for the five-month period May through September. The maximum drawdowns for these two periods were also determined. Table M-36 shows the percentage of the months during the three-month period and the five-month period that the magnitudes of drawdown indicated might occur for the reservoirs considered. For the three-month period the percentages range from seven to nineteen plus for a drawdown of ten feet, and from two to eight percent for a drawdown of 15 feet. The corresponding percentages for the five-month period are slightly higher.

TABLE M-36

PERCENT OF OCCURRENCES OF RESERVOIR DRAWDOWN EQUALLED OR EXCEEDED DURING RECREATION SEASON

	Drawdown during June, July and August					Drawdown during May through September					
	10'	15'	17'	20'	Max.	10'	15'	17'	20'	23'	Max.
	Percent of Occurrence 1/				Feet	Percent of Occurrence 1/					Feet
Hawk Mountain	19	5	2	-	18	22	8	4	2	1-	25
Tocks Island	5	-	-	-	14	8	3	2	1-	-	20
Aquashicola	10	2	1-	-	17	13	4	3	1	1-	23
Beltzville	8	2	-	-	15	10	5	3	2	1	25
Trexler	10	6	5	4	30	14	7	6	4	3	41
Maiden Creek	7	5	5	4	34	9	5	5	4	4	34
Newark	13	8	4	2	23	12	7	4	2	1	30

1/ Values represent percent of recreation months during which indicated drawdowns would be equalled or exceeded.

(Added Nov. 1960)

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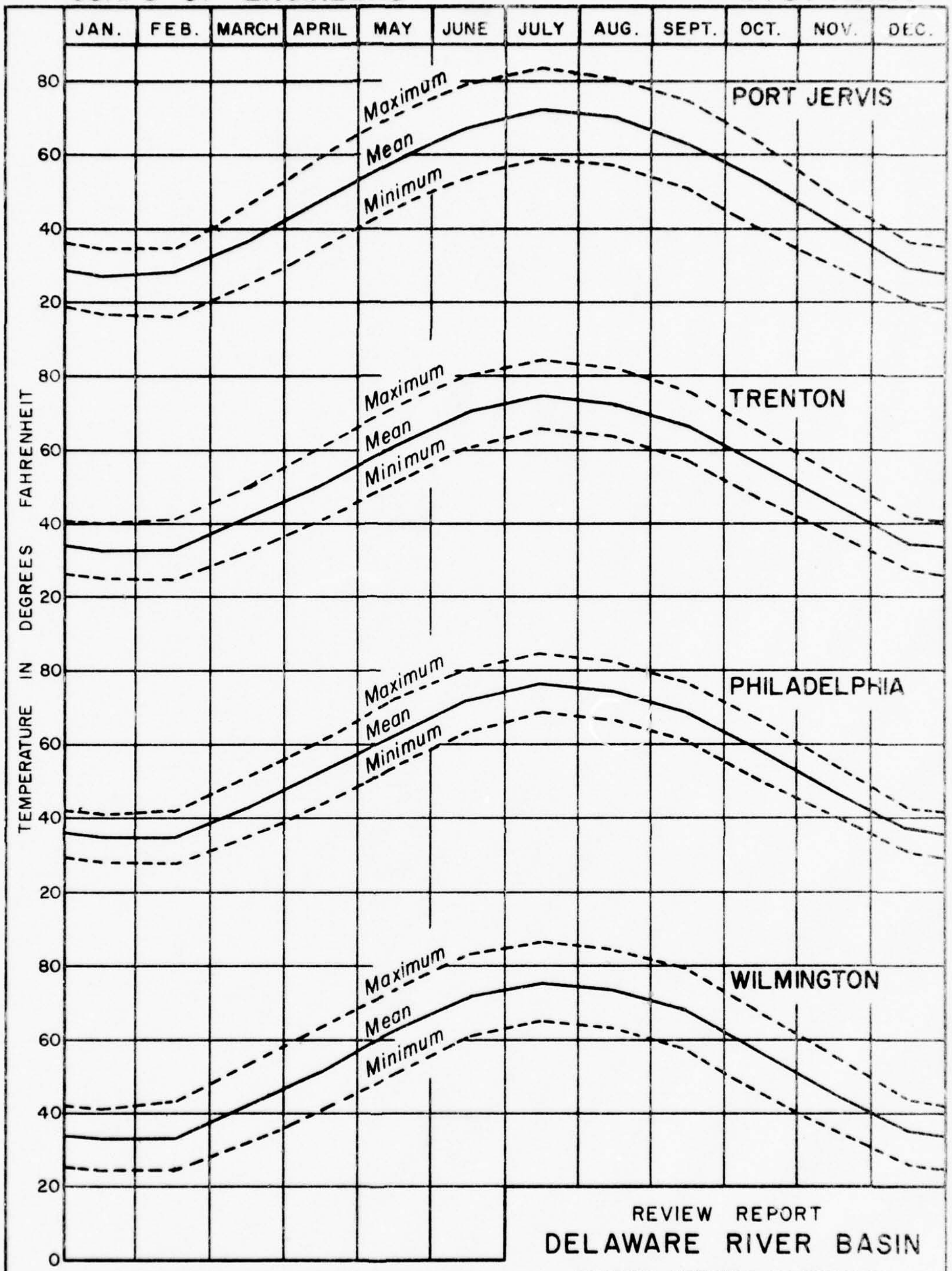


REVIEW REPORT

DELAWARE RIVER BASIN

MONTHLY NORMALS OF MAXIMUM, MINIMUM, & MEAN TEMPERATURE

In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scales as Shown
Philadelphia District
23 Oct. 1959

Drawer No. 228

File No. 28076

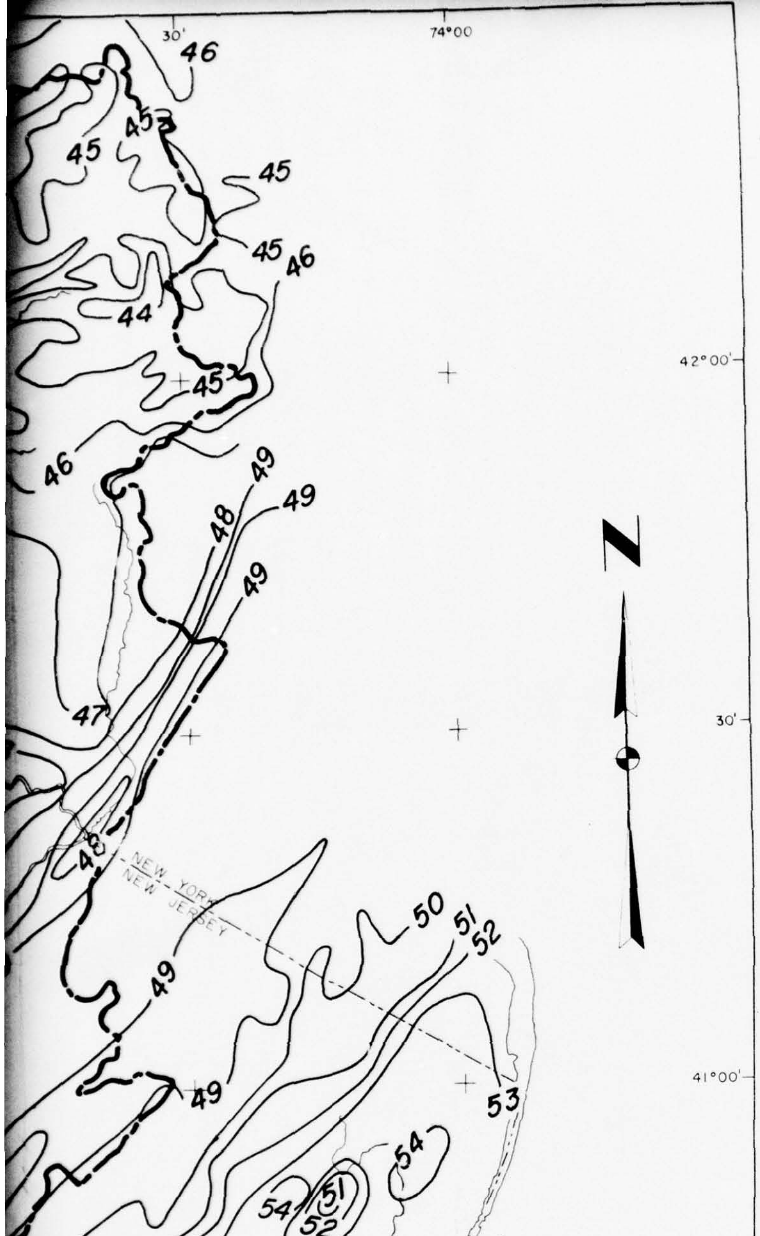
Note: Curves are plotted from data shown in Table 1.

PLATE NO. 1

CORPS OF ENGINEERS U.S. ARMY

76°30'
76°00'
30'
75°00'
30'
NEW YORK
PENNSYLVANIA
NEW YORK
NEW JERSEY
Lehigh
River
Schuylkill
R
RIVER
Raritan R
44
45
46
47
48
49
50
51
52
53
54
55

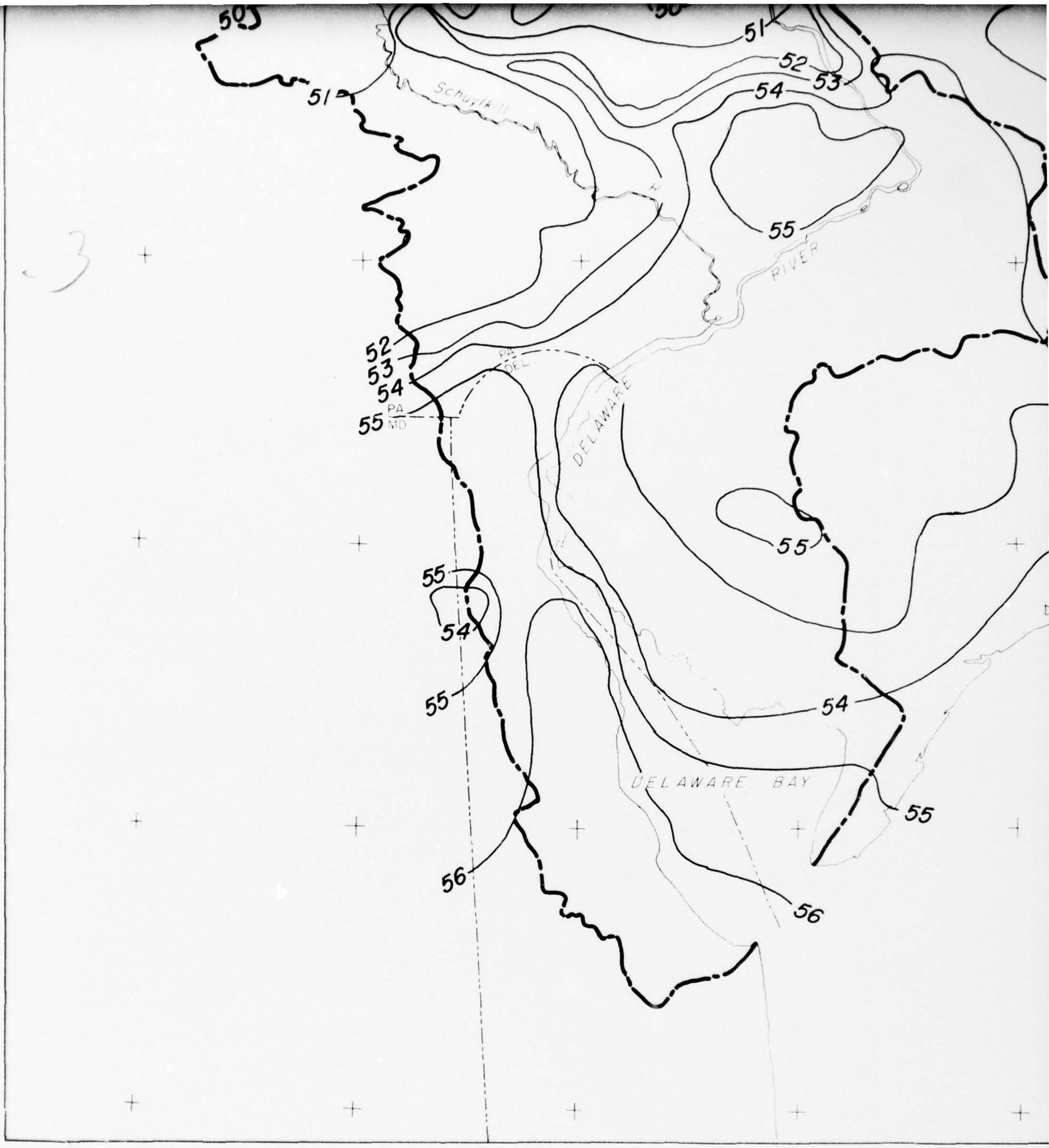
2



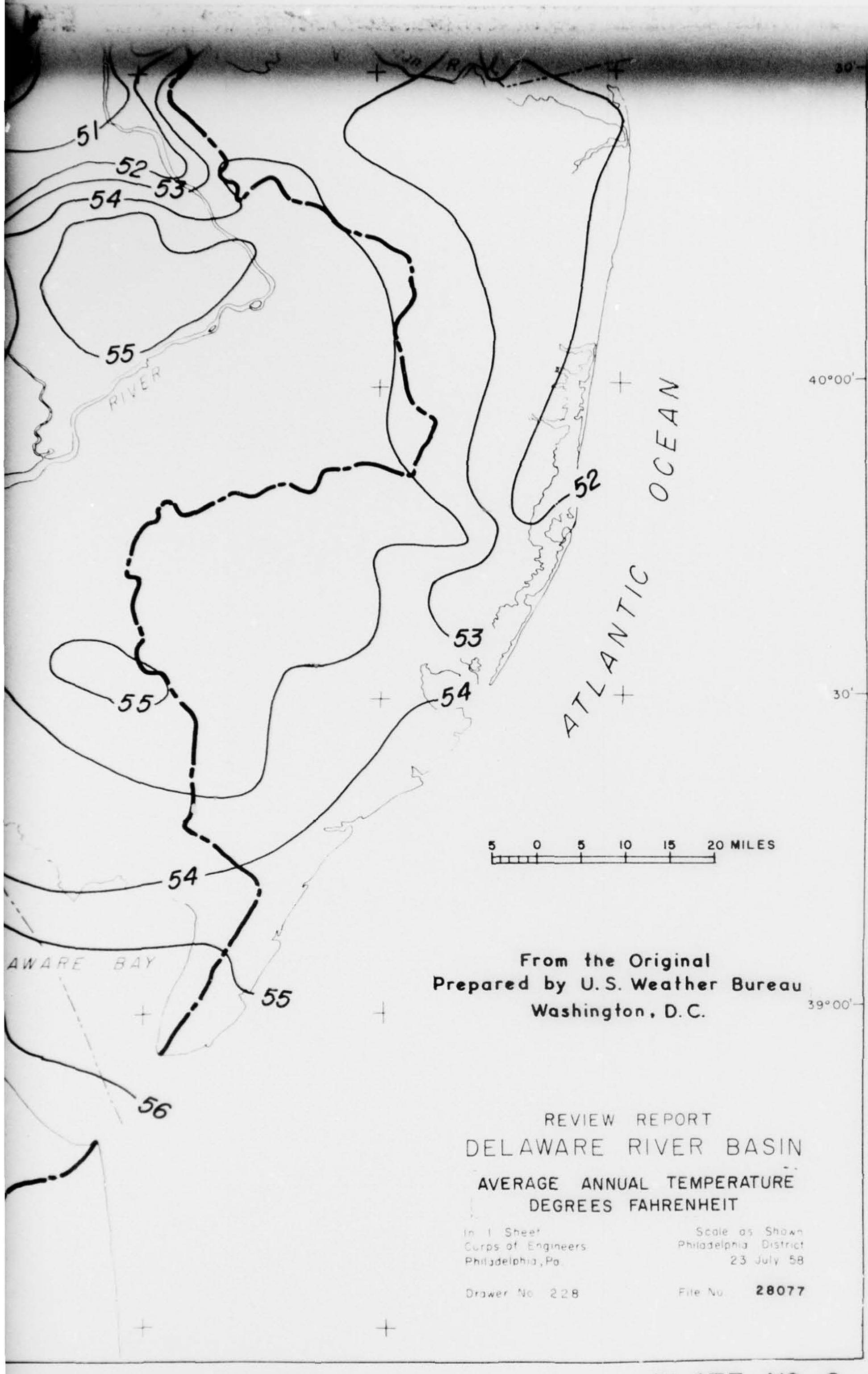
ASIN

Shown
District
ct 1959

083



Schuylkill
R
RIVER
DELAWARE
PA
DEL
PA
MD
DELAWARE BAY
50
51
51
52
53
54
55
52
53
54
55
55
54
55
55
54
55
56
56



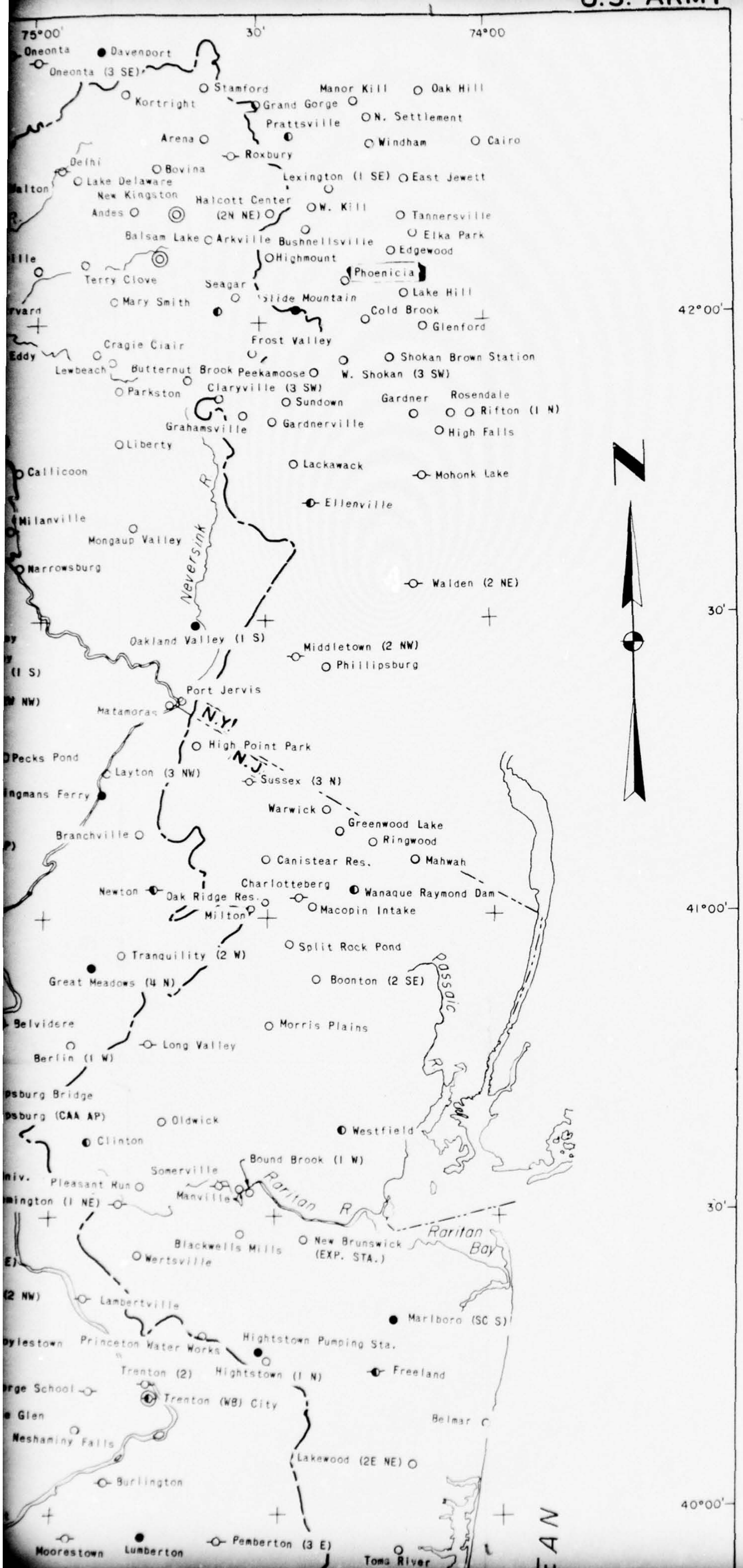
51
52
53
54
55
RIVER
52
53
54
55
54
55
56
AWARE BAY
ATLANTIC OCEAN
30'
40°00'
30'
39°00'
5 0 5 10 15 20 MILES
From the Original
Prepared by U.S. Weather Bureau
Washington, D.C.
REVIEW REPORT
DELAWARE RIVER BASIN
AVERAGE ANNUAL TEMPERATURE
DEGREES FAHRENHEIT
In 1 Sheet
Corps of Engineers
Philadelphia, Pa.
Scale as Shown
Philadelphia District
23 July 58
Drawer No. 228
File No. 28077

PLATE NO. 2

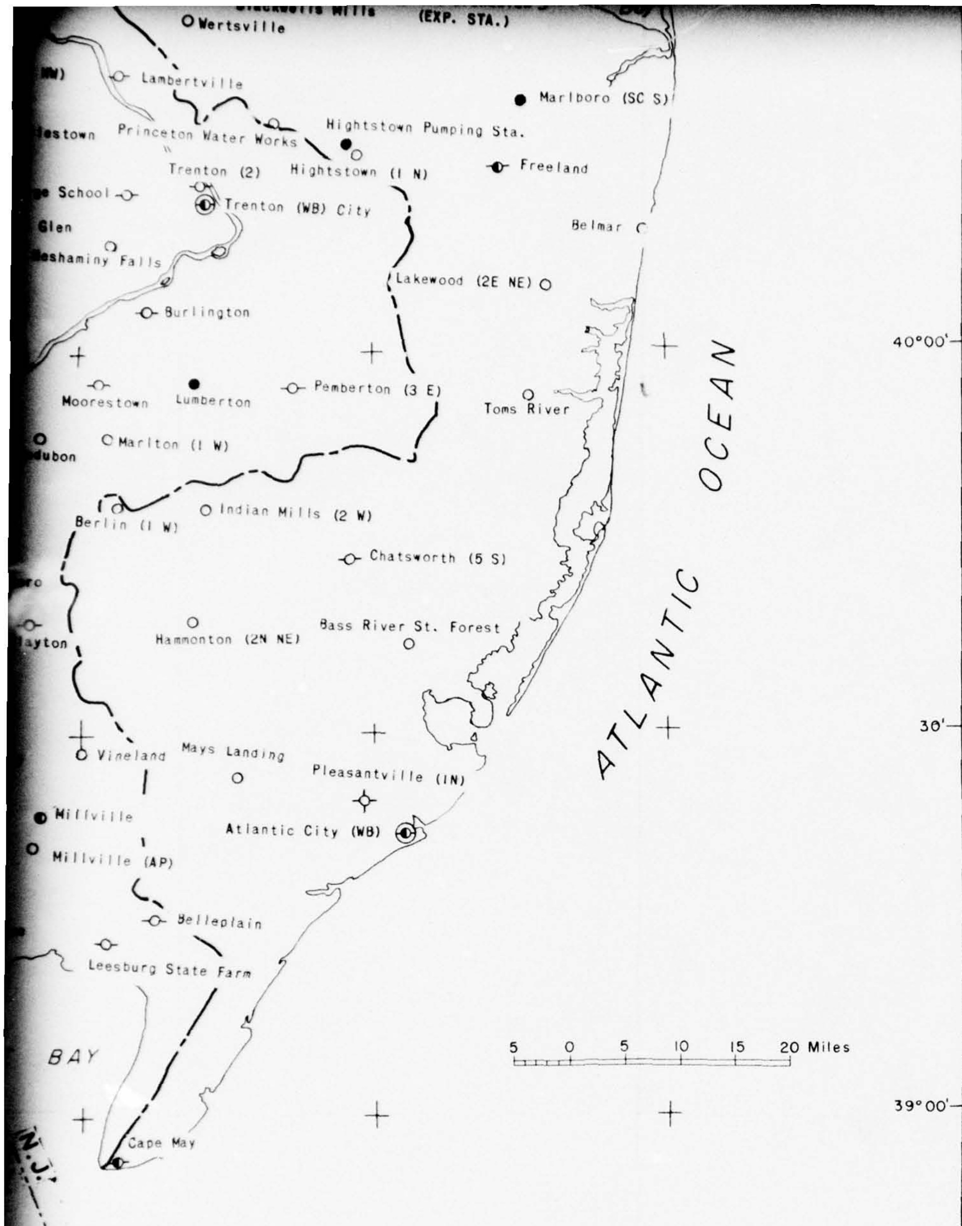

76°30'
76°00'
30'
75°00'
30'
STATION LEGEND
Precipitation only
Precipitation and temperature
Precipitation, temperature & evaporation
TYPE OF GAGE
Recording
Non-recording
Both Types
Double circle combination indicates the availability of more detailed meteorological data.
Oneonta
Davenport
Oneonta (3 SE)
Stamford
Kortright
Manor Kill
Grand Gorge
Prattsville
Rockdale
E. Sidney
Green
Unadilla
Arena
Roxbury
Delhi
Bovina
Lexington (1 SE)
Walton
Lake Delaware
New Kingston
Halcott Center (2N NE)
W. Kill
Andes
Binghamton (WB-AP)
China
Balsam Lake
Arkville
Bushnellsville
China (2)
W. Br. Delaware R.
Downsville
Highmount
Binghamton
Terry Clove
Seagar
Slide Mountain
Hale Eddy (4N NW)
Mary Smith
Harvard
Frost Valley
Cragie Clair
Fishs Eddy
Susquehanna
Lewbeach
Butternut Brook
Peekamoose
W. Shoka
Parkston
Claryville (3 SW)
Sundown
Equinunk (2)
Grahamsville
Gardnerville
Montrose (1 E)
Liberty
Lackawack
Callicoon
Pleasant Mount (1 W)
Ellenville
Hop Bottom (2 SE)
Milanville
Honesdale (6N NW)
Mongaup Valley
Neversink R.
Honesdale (4 NW)
Narrowsburg
Dixon
South Canaan (1 NE)
Hawley
Oakland Valley (1 S)
Middletown (2
Hawley Site (1 S)
Phillipsb
Scranton
Hollisterville
Paupack (2W NW)
Port Jervis
Lakeville (1N NE)
Matamoras
N.Y.
N.J.
High Point Park
Wilkes Barre
Pecks Pond
Gouldsboro
Layton (3 NW)
Sussex (3 N)
Dingmans Ferry
Meadow Run Ponds
Warwick
Greenwo
Branchville
Mt. Pocono (2N AP)
Canistear Res.
Blakeslee Corner
Charlotteberg
Wanaq
Long Pond (2N)
Newton
Oak Ridge Res.
Macopin Int
Freeland
Pimple Hill
Milton
Stroudsburg
Split Rock Pon
Merwinsburg
Tranquility (2 W)
Zion Grove
Portland
Kresgeville (3 W)
Portland
Great Meadows (4 N)
Boonton (2
Tamaqua Dam
Jim Thorpe
Bear Gap
Coaldale (2 NW)
Lansford
Lehighton
Wind Gap
Belvidere
Morris Plains
Tamaqua
Palmerton
Berlin (1 W)
Long Valley
Gordon
Phillipsburg Bridge
Pottsville
New Tripoli
Allentown (WB AP)
Phillipsburg (CAA AP)
Oldwick
Westfi
Claussville
Clinton
Port Clinton
Bethlehem
Bound Brook (1 W)
Pine Grove (1 NE)
Allentown Gas Co.
Bethlehem Lehigh Univ.
Pleasant Run
Somerville
Raritan R.
Virginville
Flemington (1 NE)
Manville
Berne
Strausstown
Fredericksville
Zionsville (3 SE)
Blackwells Mills
New Brunswick (EXP. STA.)
Barto (4 NW)
Palm
Quakertown (1 E)
Wertsville
Myerstown
Sellersville (2 NW)
Lambertville
Lebanon (3 SW)
Lebanon (3 W)
Wernersville (1 W)
Reading City (WB)
Schuylkill
Doylestown
Princeton Water Works
Hightstown Pumping Sta.
Pottstown
Trenton (2)
Hightstown (1 N)
Mt. Gretna (2 SW)
Graterford
George School
Georgetown
Ephrata
Trenton (WB) City
Maple Glen
Morgantown
Landisville (2 NW)
Neshaminy Falls
Phoenixville (1 E)
River
Lakewood (2E NE
Lancaster (2NE PUMP)
Norristown
Burlington
Devault (1 W)
Conshohocken
Lancaster (2NE FLTR)
Coatesville
Philadelphia Shawmont
Phila. Drexel Inst. of Tech.
Coatesville (1 SW)
Upper Darby
Moorestown
Lumberton
Pemberton (3 E)
West Chester
Philadelphia Pt. Breeze
Toms

U.S. ARMY

2


75°00'
30'
74°00
42°00'
30'
41°00'
30'
40°00'
Oneonta
Davenport
Oneonta (3 SE)
Stamford
Kortright
Grand Gorge
Manor Kill
Oak Hill
N. Settlement
Prattsville
Windham
Cairo
Arena
Roxbury
Delhi
Bovina
Lexington (1 SE)
East Jewett
Walton
Lake Delaware
New Kingston
Halcott Center (2N NE)
W. Kill
Tannersville
Andes
Elka Park
Balsam Lake
Arkville
Bushnellsville
Edgewood
Highmount
Phoenicia
Terry Clove
Seagar
Lake Hill
Mary Smith
Slide Mountain
Cold Brook
Glenford
Frost Valley
Cragie Clair
Eddy
Shokan Brown Station
Lewbeach
Butternut Brook
Peekamoose
W. Shokan (3 SW)
Parkston
Claryville (3 SW)
Sundown
Gardner
Rosendale
Rifton (1 N)
Grahamsville
Gardnerville
High Falls
Liberty
Lackawack
Callicoon
Mohonk Lake
Ellenville
Milanville
Mongaup Valley
Neversink R.
Narrowsburg
Walden (2 NE)
Oakland Valley (1 S)
Middletown (2 NW)
Phillipsburg
Port Jervis
Matamoras
N.Y.
N.J.
High Point Park
Pecks Pond
Layton (3 NW)
Sussex (3 N)
Dingmans Ferry
Warwick
Greenwood Lake
Ringwood
Branchville
Canistear Res.
Mahwah
Charlotteberg
Newton
Oak Ridge Res.
Wanaque Raymond Dam
Macopin Intake
Milton
Split Rock Pond
Tranquility (2 W)
Passaic R.
Great Meadows (4 N)
Boonton (2 SE)
Belvidere
Morris Plains
Long Valley
Berlin (1 W)
Phillipsburg Bridge
Phillipsburg (CAA AP)
Oldwick
Westfield
Clinton
Bound Brook (1 W)
Somerville
Pleasant Run
Manville
Raritan R.
Flemington (1 NE)
Raritan Bay
Blackwells Mills
New Brunswick (EXP. STA.)
Wertsville
Lambertville
Marlboro (SC S)
Doylestown
Princeton Water Works
Hightstown Pumping Sta.
Trenton (2)
Hightstown (1 N)
Freeland
George School
Trenton (WB) City
Glen
Belmar
Neshaminy Falls
Lakewood (2E NE)
Burlington
Moorestown
Lumberton
Pemberton (3 E)
Toms River
EAN
N


Lebanon (3 SW)
Lebanon (3 W)
Wernersville (1 W)
Reading City (WB)
Lambertville
Schuylkill
River
Pottstown
Doylestown
Princeton Water Works
Hightstown Pump
Hightstown (1 N)
Trenton (2)
Trenton (WB) City
Mt. Gretna (2 SW)
Ephrata
Georgetown
Graterford
George School
Maple Glen
Neshaminy Falls
Morgantown
Landisville (2 NW)
Phoenixville (1 E)
Norristown
Lakewood
Lancaster (2NE PUMP)
Lancaster (2NE FLTR)
Devault (1 W)
Conshohocken
Burlington
Coatesville
Philadelphia Shawmont
Phila. Drexel Inst. of Tech.
Upper Darby
Coatesville (1 SW)
West Chester
Moorestown
Lumberton
Pemberton (3 E)
Philadelphia Pt. Breeze
Philadelphia (WB-AP)
Audubon
Marlton (1 W)
West Grove (1 SE)
Chadds Ford
PA.
DEL.
Marcus Hook
Swedesboro (5 NW)
Berlin (1 W)
Indian Mills (2 W)
Wilmington Porter Res.
Wilmington City Hall
PA.
MD.
Wilmington N. Castle
(WB-AP)
Chatsworth
Deepwater
Glassboro
Conowingo Dam
Conowingo Police Brks.
Woodstown (2 NW)
Clayton
Hammonton (2N NE)
Bass River St. Fo
Elkton
Perry Point
Centerton
Bridgeton (1 NE)
Vineland
Mays Landing
Aberdeen Phillips Fld.
Canton
Pleasantville (1N)
Millville
Middletown (2 S)
Atlantic City (WB)
Coleman (3WNW)
Millville (AP)
Millington
Fortescue
Belleplain
Chestertown
Leesburg State Farm
Dover
DELAWARE BAY
Centreville
DEL.
MD.
Cape May
N.J.
DEL.
Milford
Denton
Lewes
Bridgeville (1 NW)
Preston (1 S)
Georgetown (5 SW)



REVIEW REPORT

DELAWARE RIVER BASIN

PRECIPITATION STATIONS

In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scale as Shown
Philadelphia District
23 July 58

Drawer No. 228

File No. 28078

PLATE NO. 3

4

CORPS OF ENGINEERS U.S. ARMY

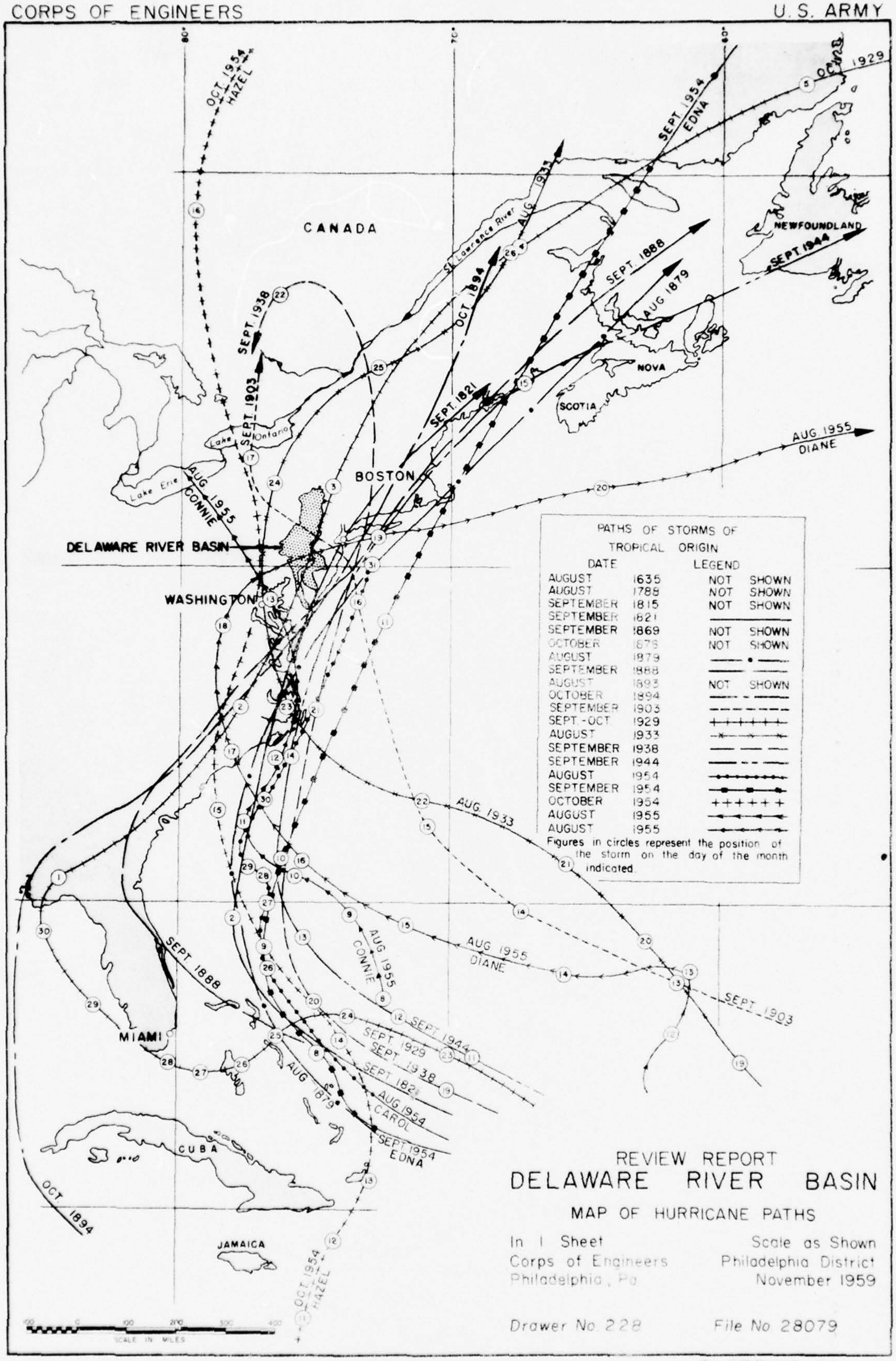
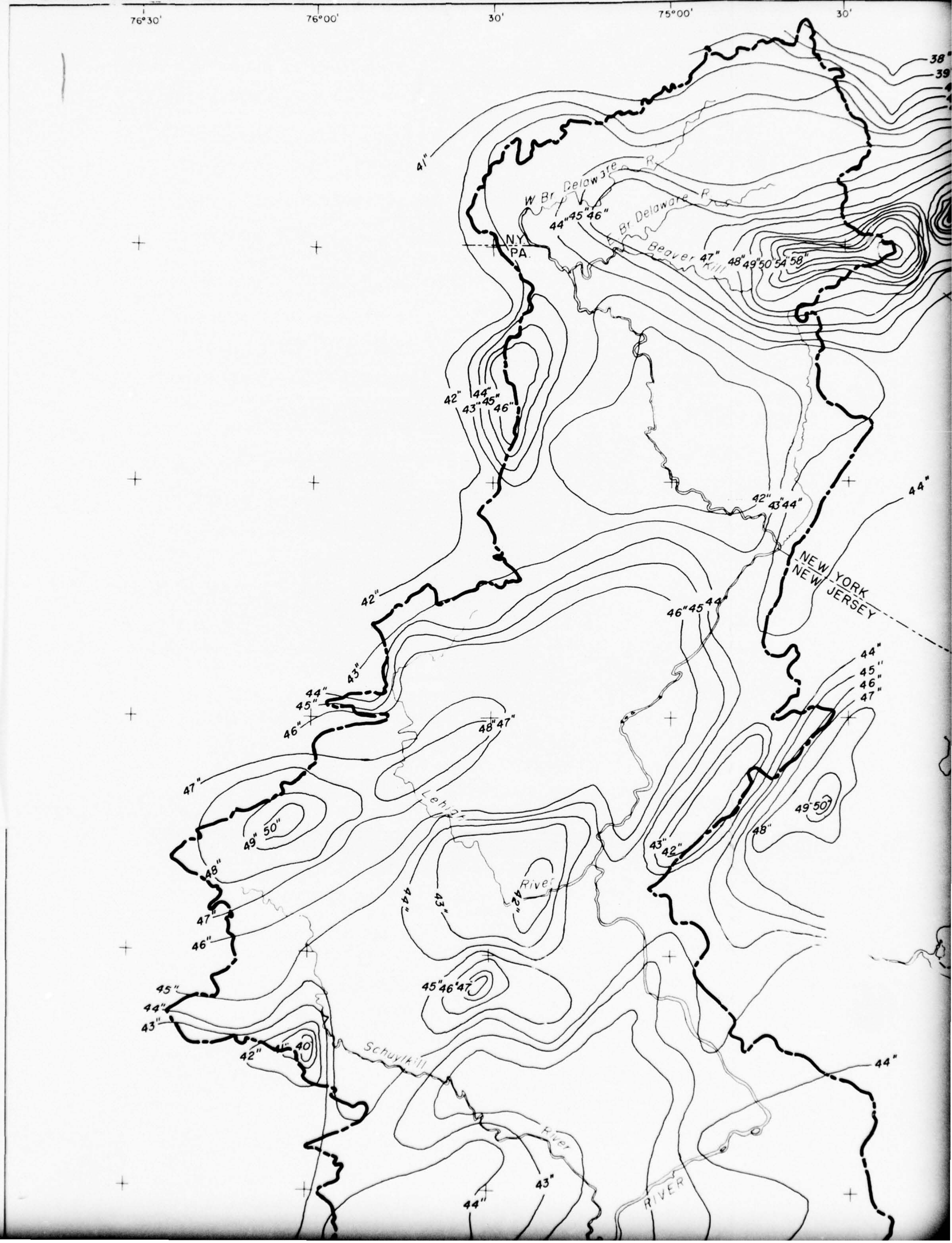


PLATE NO. 4

CORPS OF ENGINEERS



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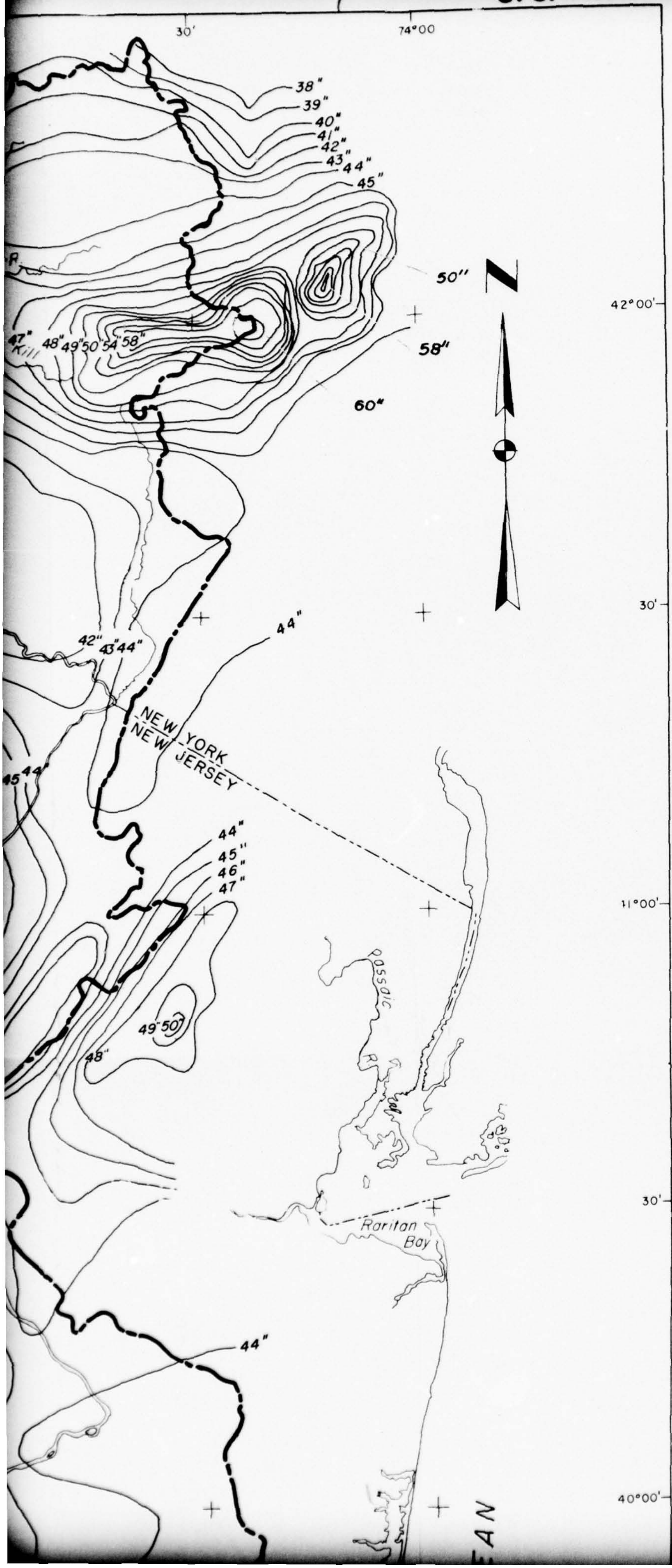
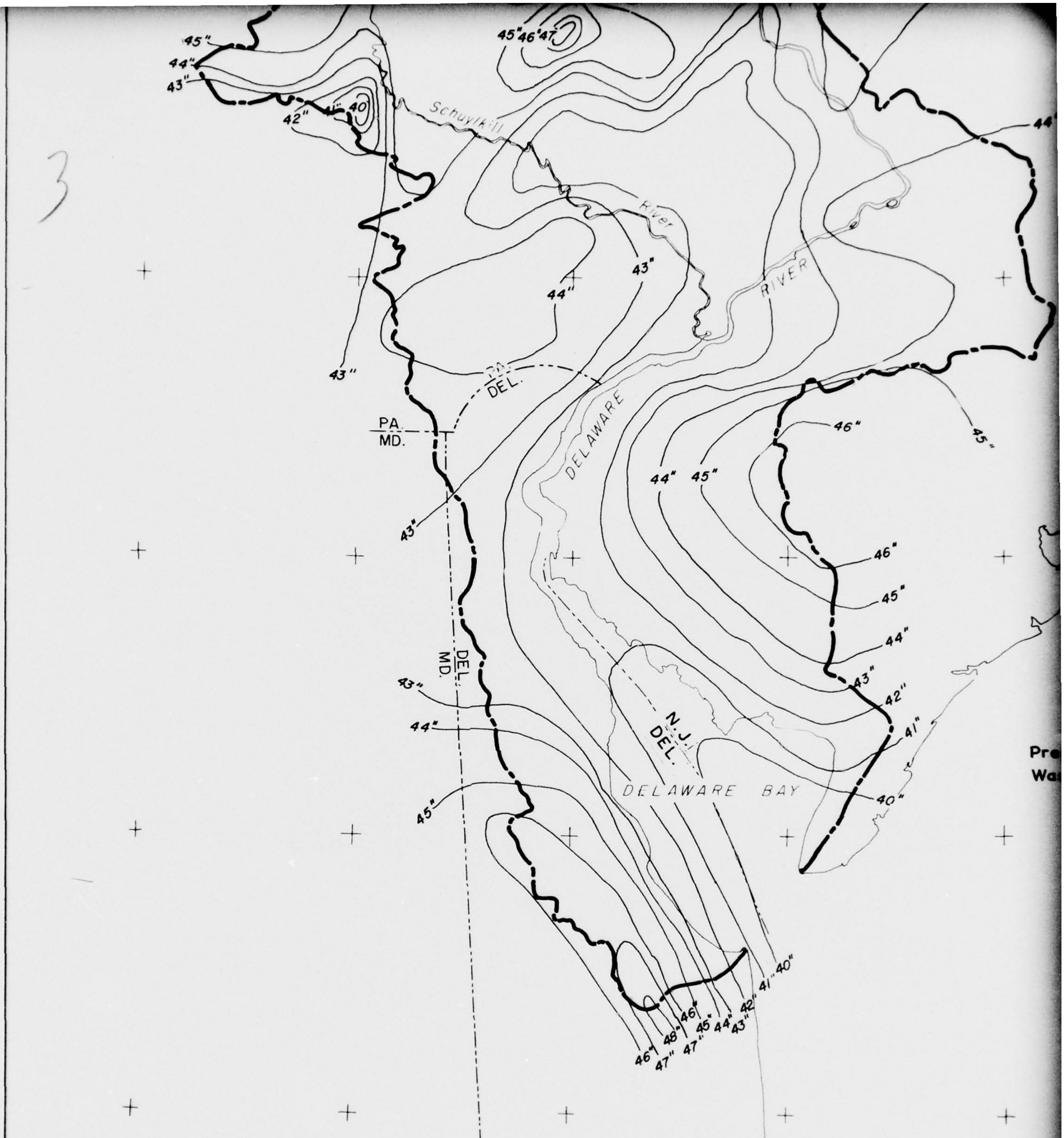

30'
74°00
38"
39"
40"
41"
42"
43"
44"
45"
50"
58"
60"
47"
Kill
48" 49" 50 54" 58"
42°00'
30'
42"
43" 44"
44"
NEW YORK
NEW JERSEY
45 44
44"
45"
46"
47"
41°00'
Passaic
R.
49 50
48"
30'
Raritan
Bay
44"
40°00'
EAN

3



45"
44"
43"
42"
40
45" 46" 47
Schuylkill
River
43"
44"
43"
RIVER
44"
PA.
DEL.
PA.
MD.
DELAWARE
46"
45"
44" 45"
43"
46"
45"
44"
43"
42"
41"
DEL.
MD.
43"
44"
N.J.
DEL.
DELAWARE BAY
40"
45"
41" 40"
42"
46" 45" 44" 43"
48"
46" 47" 47"

Pre
Wa

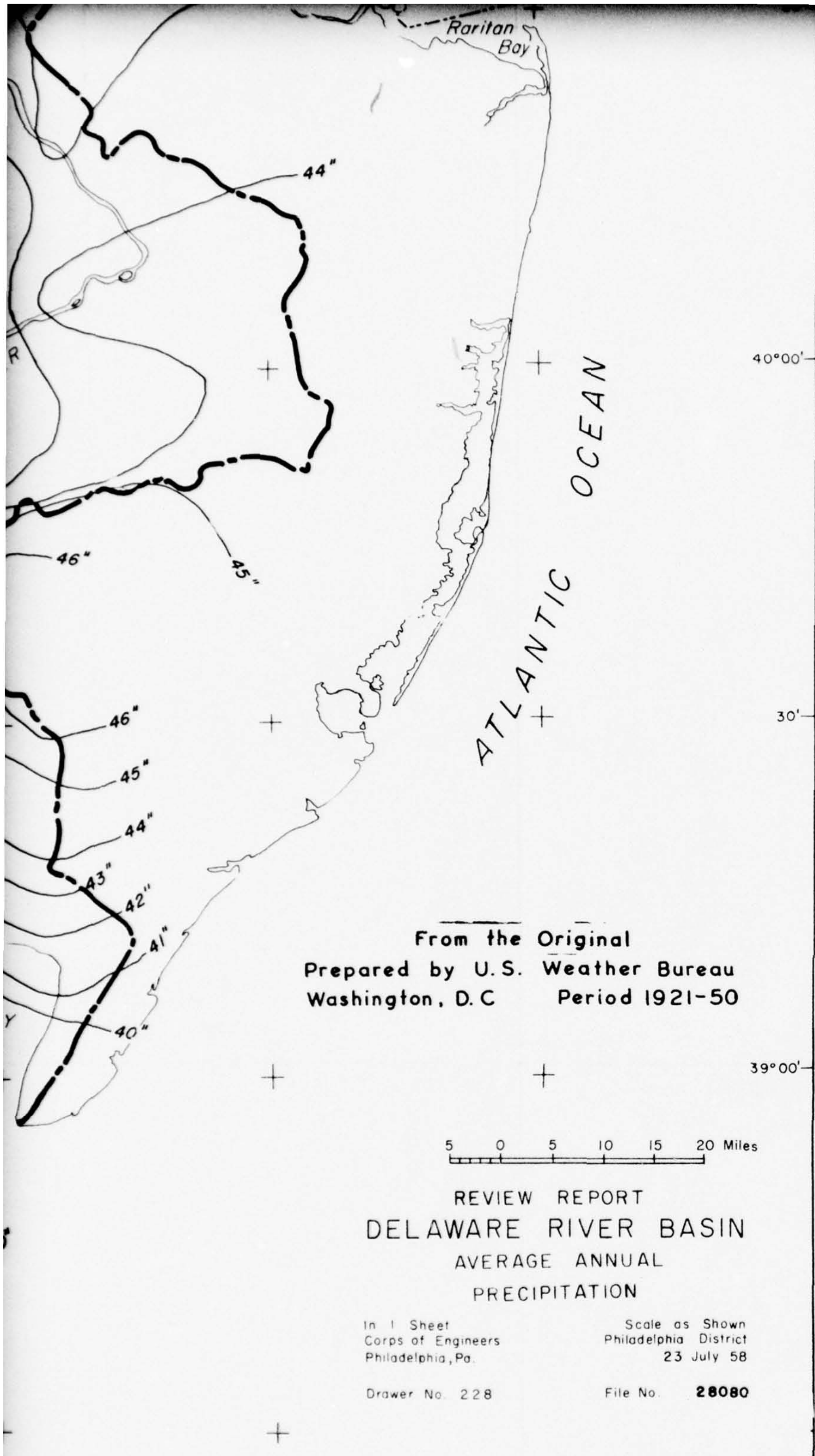
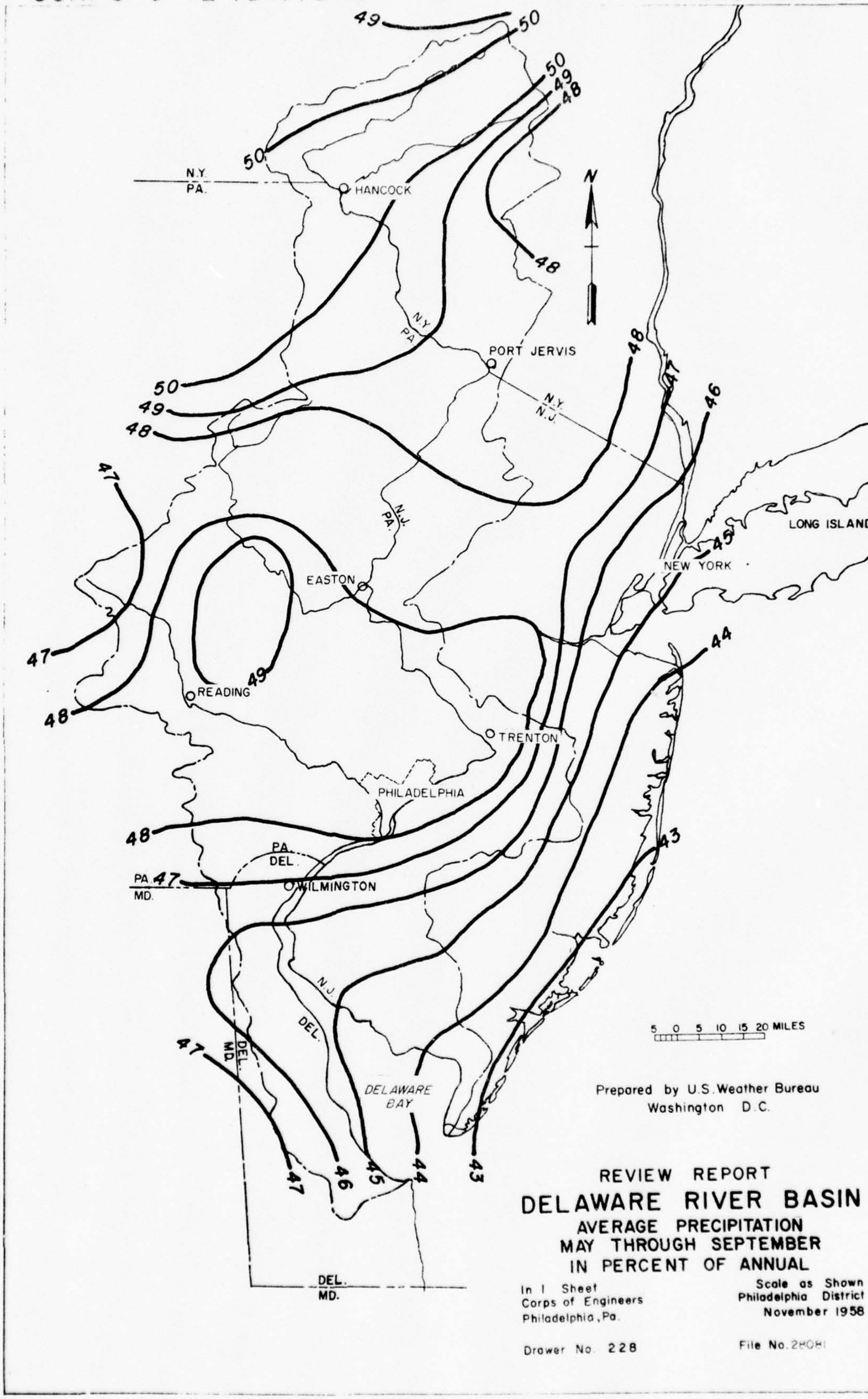

Raritan Bay
44"
40°00'
ATLANTIC OCEAN
46"
45"
30'
46"
45"
44"
43"
42"
41"
40"
From the Original
Prepared by U.S. Weather Bureau
Washington, D.C Period 1921-50
39°00'
5 0 5 10 15 20 Miles
REVIEW REPORT
DELAWARE RIVER BASIN
AVERAGE ANNUAL
PRECIPITATION
In 1 Sheet
Corps of Engineers
Philadelphia, Pa.
Scale as Shown
Philadelphia District
23 July 58
Drawer No. 228
File No. 28080

PLATE NO. 5

CORPS OF ENGINEERS U.S. ARMY



REVIEW REPORT

DELAWARE RIVER BASIN

AVERAGE PRECIPITATION
MAY THROUGH SEPTEMBER
IN PERCENT OF ANNUAL

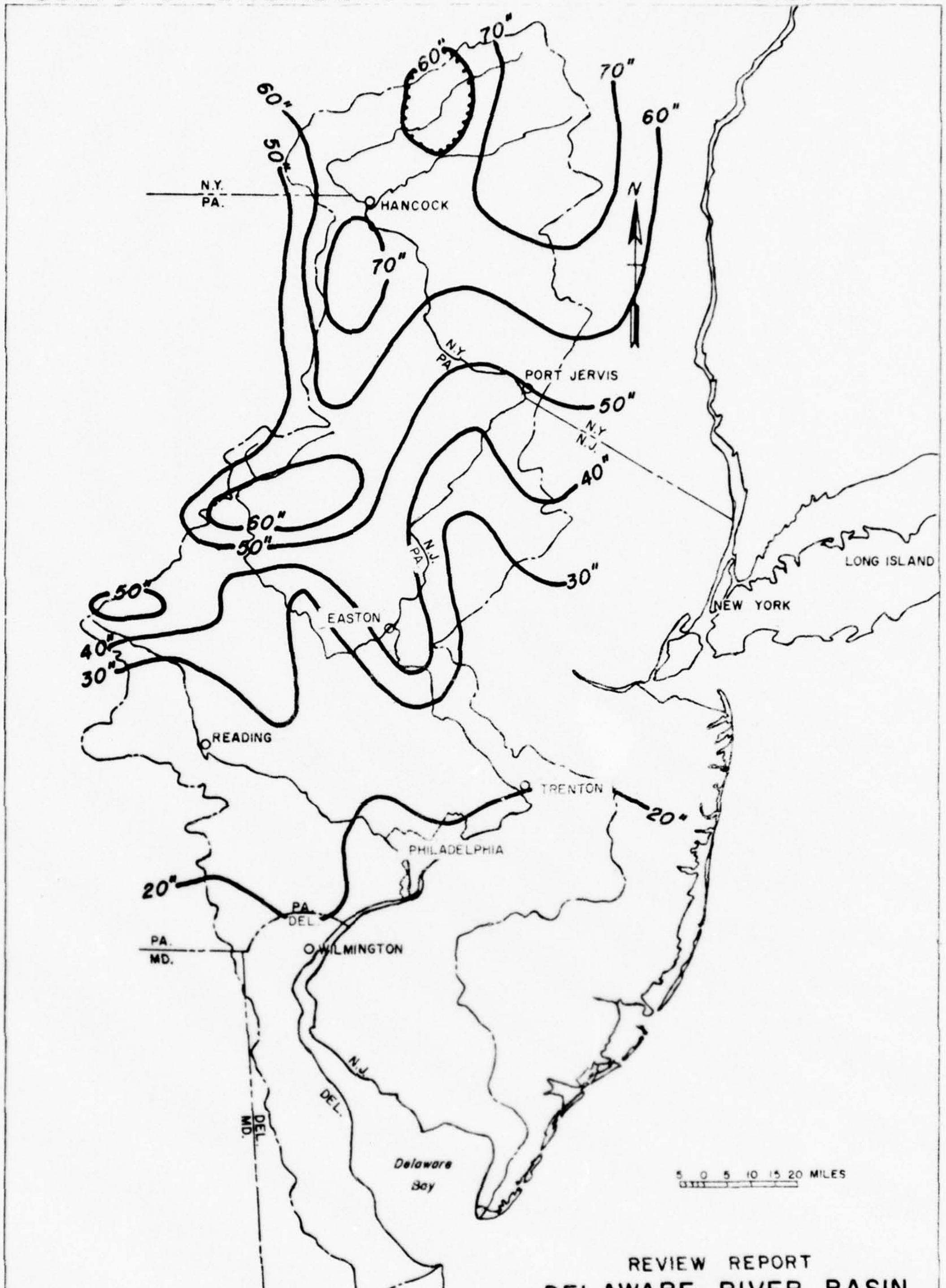
In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scale as Shown
Philadelphia District
November 1958

Drawer No. 228

File No. 28081

PLATE NO. 6



REVIEW REPORT

DELAWARE RIVER BASIN

AVERAGE ANNUAL
SNOWFALL

In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scale as Shown
Philadelphia District
November 1958

Drawer No. 228

File No. 28082

PLATE NO. 7

CORPS OF ENGINEERS U.S. ARMY

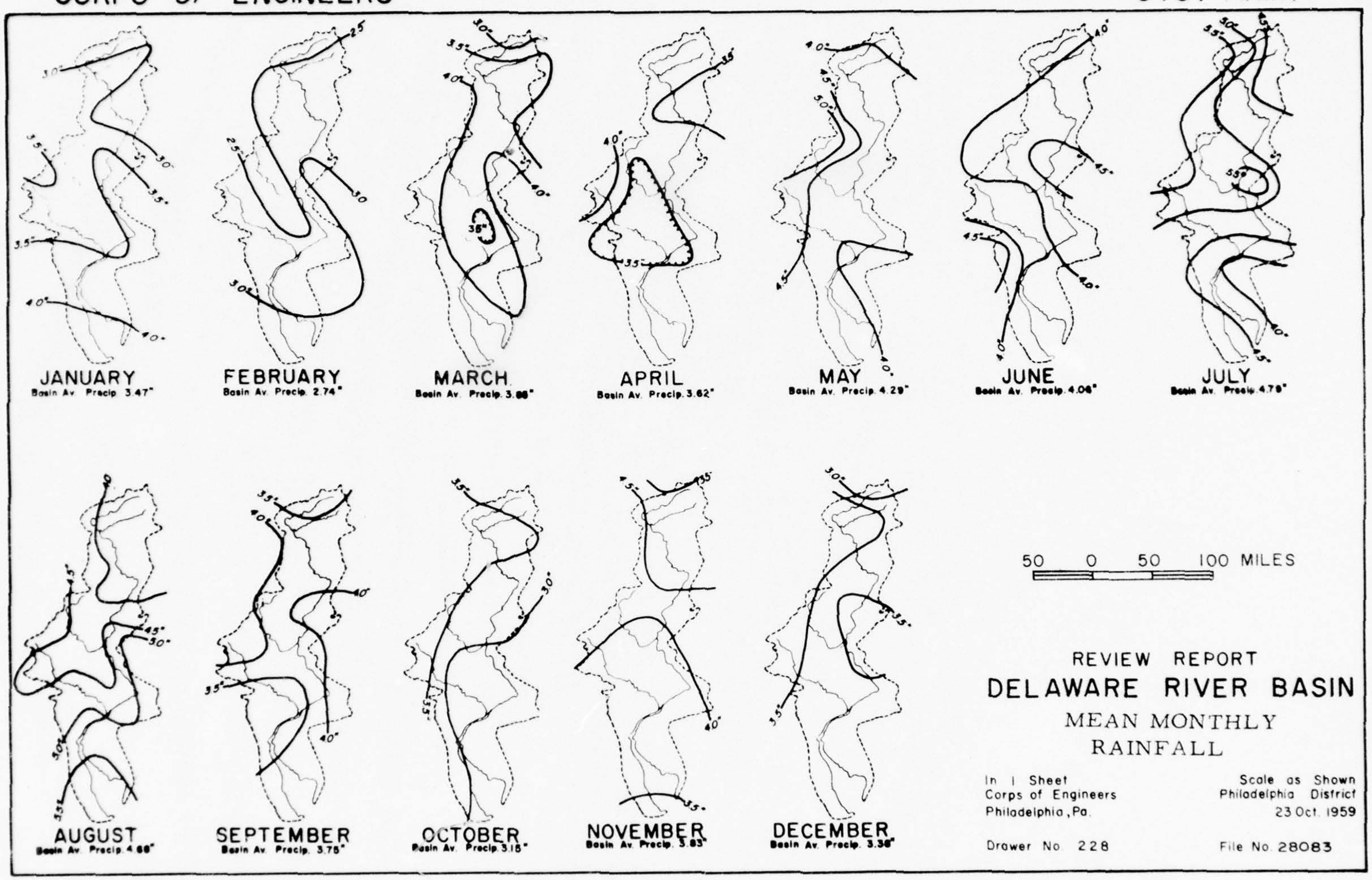
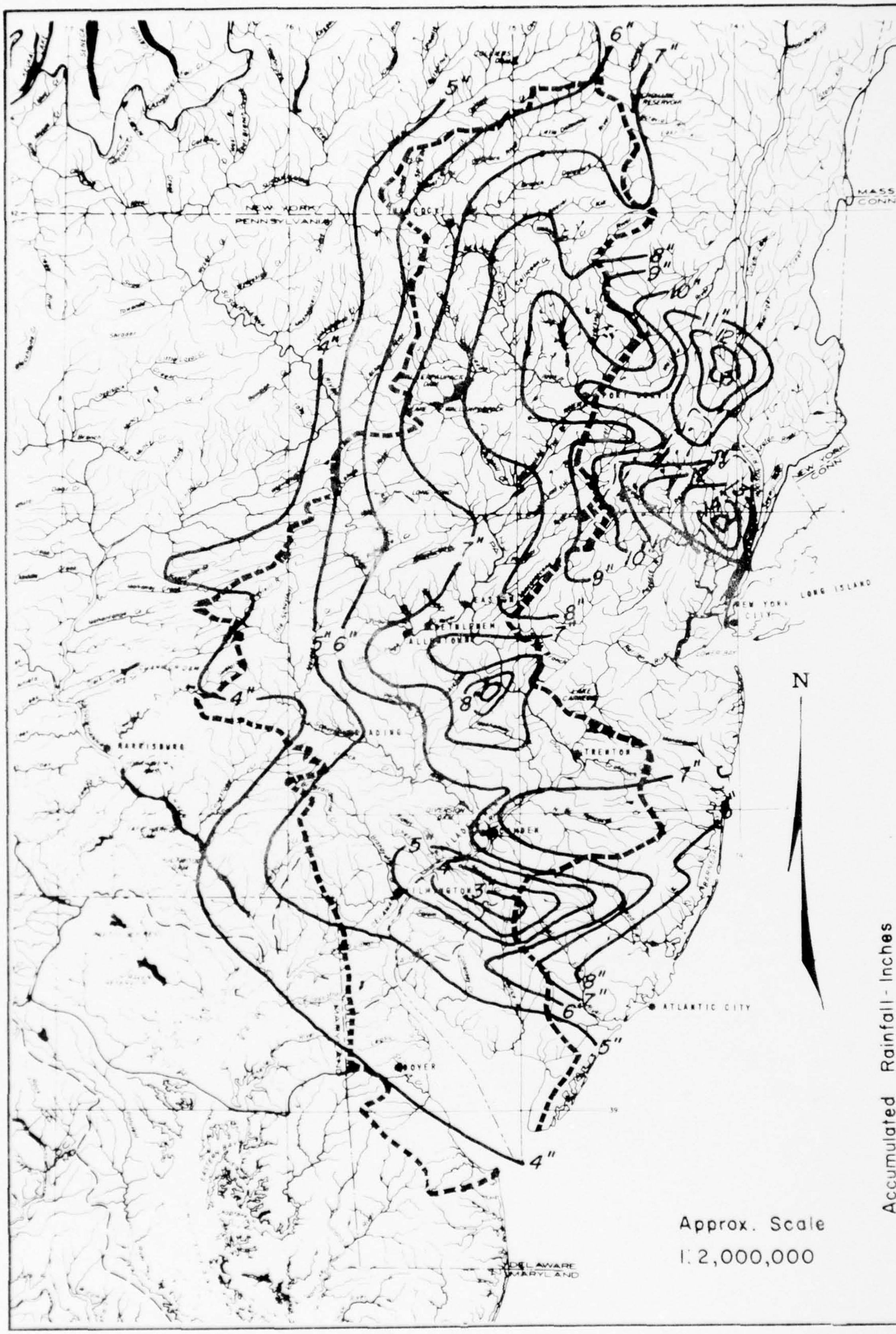
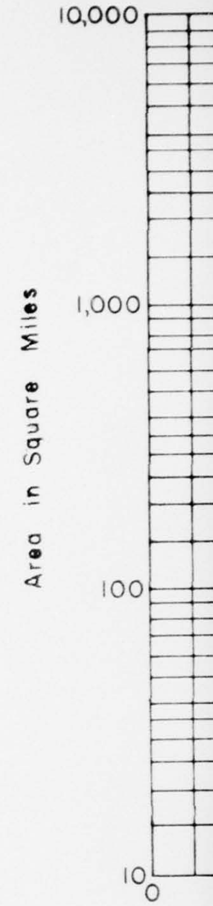


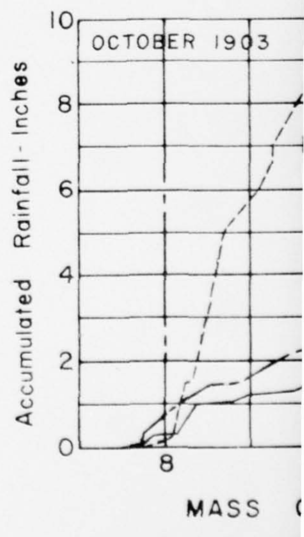
PLATE NO. 8



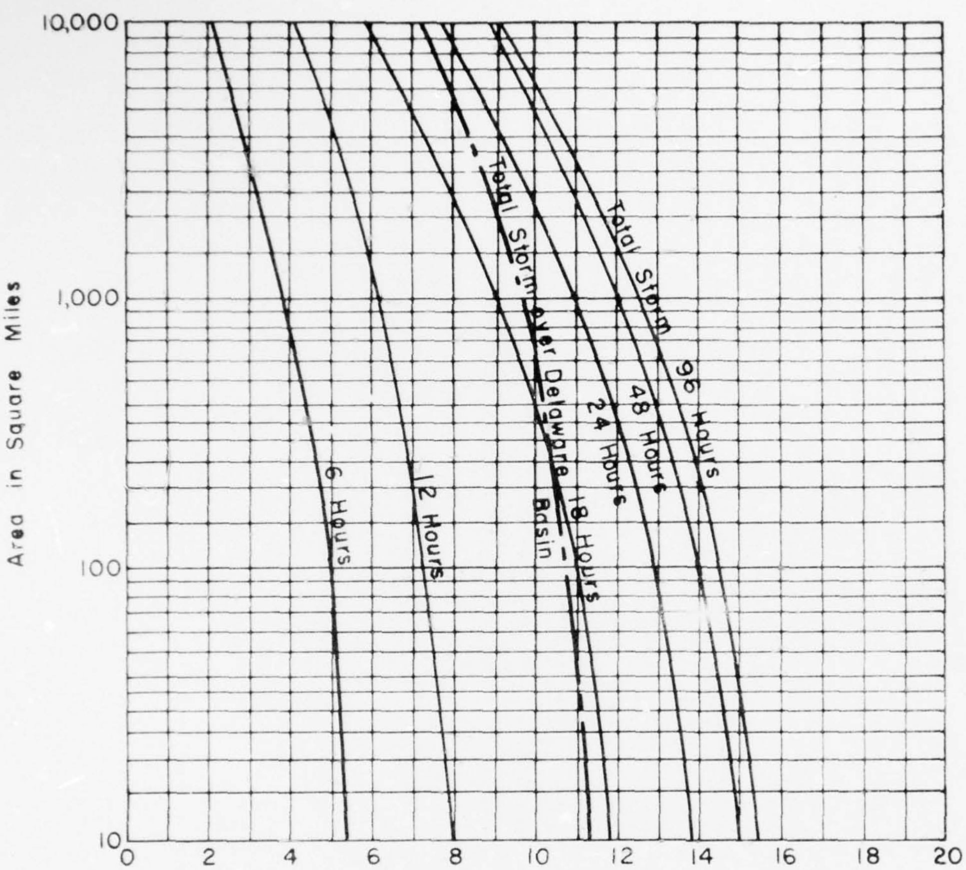
NEW YORK
PENNSYLVANIA
MASS
CONN
NEW YORK
CONN
NEW YORK CITY
LONG ISLAND
BETHLEHEM
ALLENTOWN
HARRISBURG
READING
TRENTON
ATLANTIC CITY
DOVER
DELAWARE
MARYLAND
4"
5"
6"
7"
8"
9"
10"
11"
12"
N
Approx. Scale
1: 2,000,000



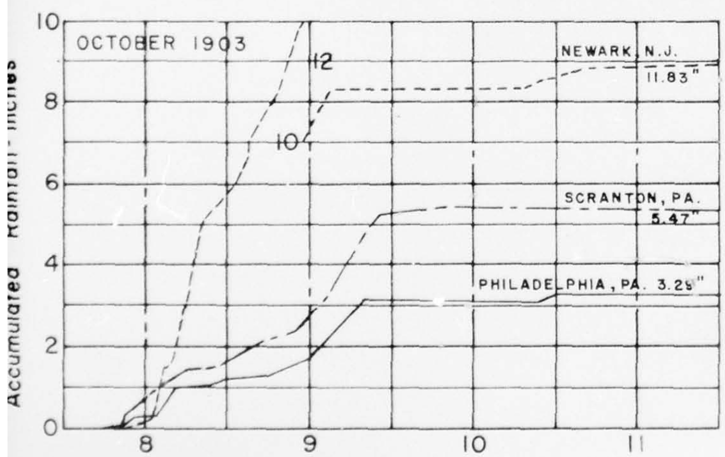
10,000
1,000
100
10
0
Area in Square Miles



OCTOBER 1903
Accumulated Rainfall - Inches
10
8
6
4
2
0
8
MASS



MAXIMUM DEPTH-AREA-DURATION CURVES



MASS CURVES OF RAINFALL

Storm Center
Paterson, N.J.

REVIEW REPORT

DELAWARE RIVER BASIN

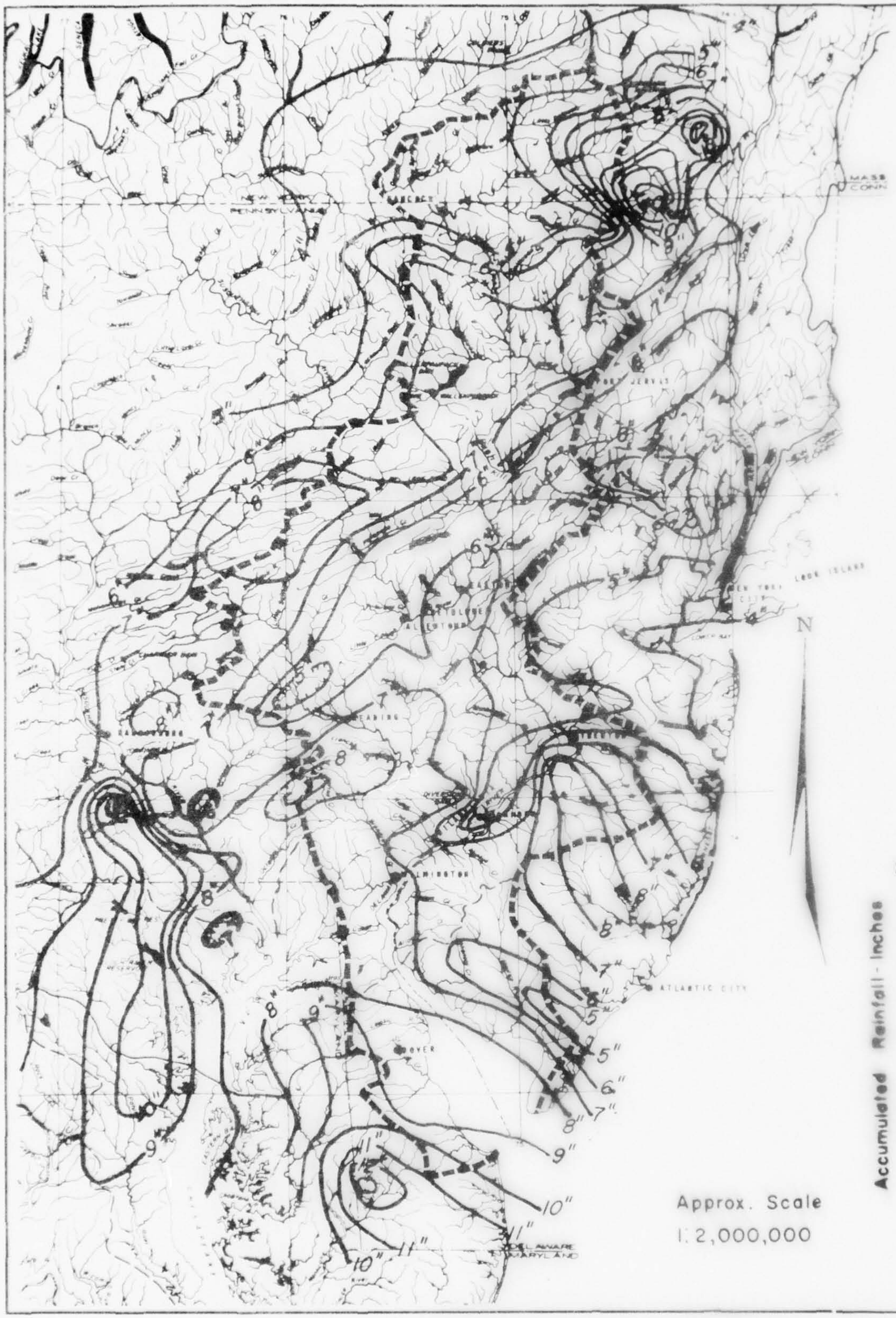
ISOHYETAL MAP
STORM OF 8-11 OCTOBER 1903

In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

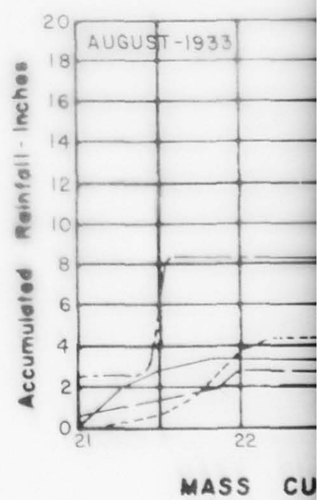
Scales as Shown
Philadelphia District
NOVEMBER 1958

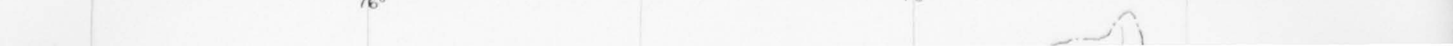
Drawer No. 228

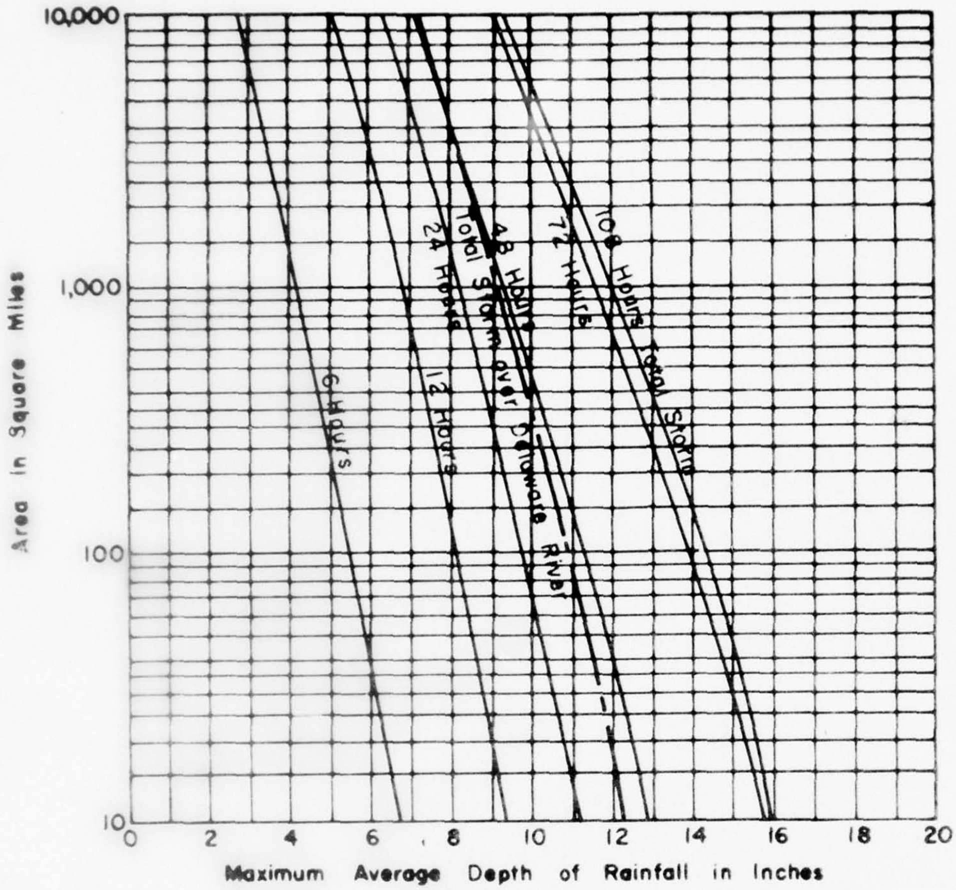
File No. 28084


MASS
CONN
NEW YORK
PENNSYLVANIA
PORT JERVIS
ALLENTOWN
READING
NEW YORK CITY
LONG ISLAND
ATLANTIC CITY
DOVER
DELAWARE
MARYLAND
N
5"
6"
7"
8"
9"
10"
11"
Approx. Scale
1: 2,000,000

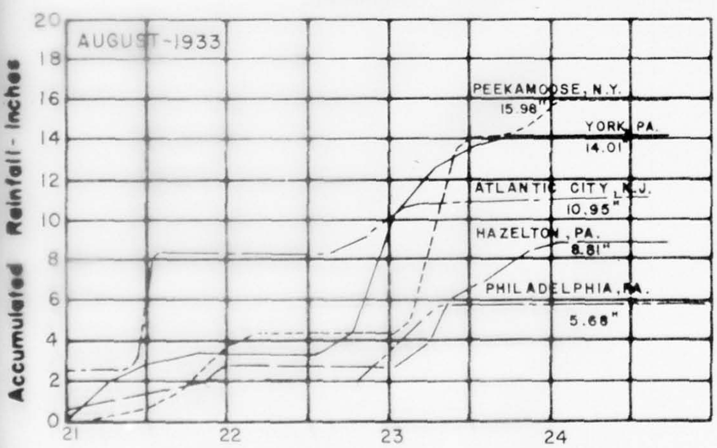

10,000
1,000
100
10
0
2
Area in Square Miles


AUGUST-1933
Accumulated Rainfall - Inches
20
18
16
14
12
10
8
6
4
2
0
21
22
MASS CU


76°
75°



MAXIMUM DEPTH-AREA-DURATION CURVES



MASS CURVES OF RAINFALL

Storm Center

Peekamoose, N.Y.

REVIEW REPORT

DELAWARE RIVER BASIN

ISOHYETAL MAP

STORM OF 20-24 AUGUST 1933

In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

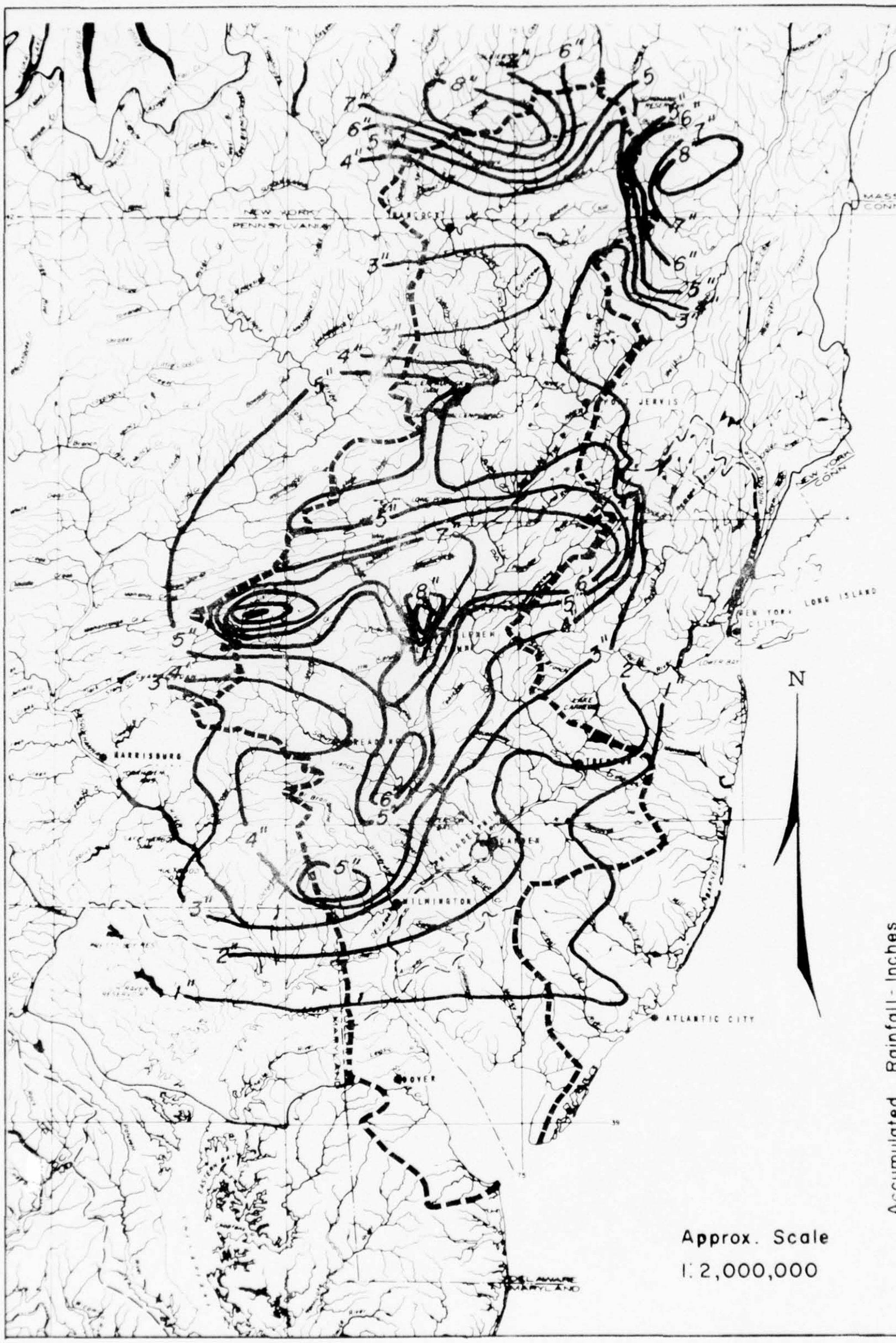
Scales as Shown
Philadelphia District
NOVEMBER 1956

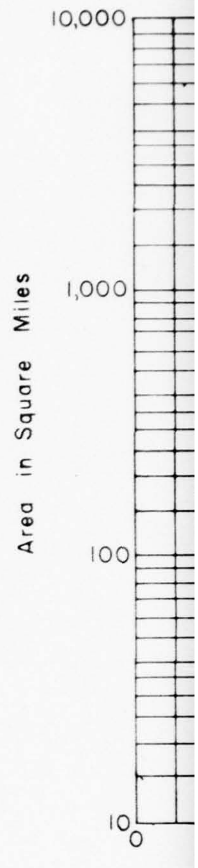
Drawer No. 228

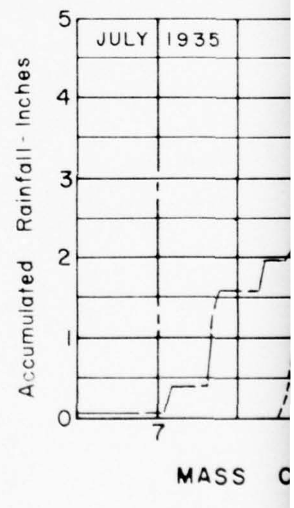
File No. 28085

PLATE No. 10

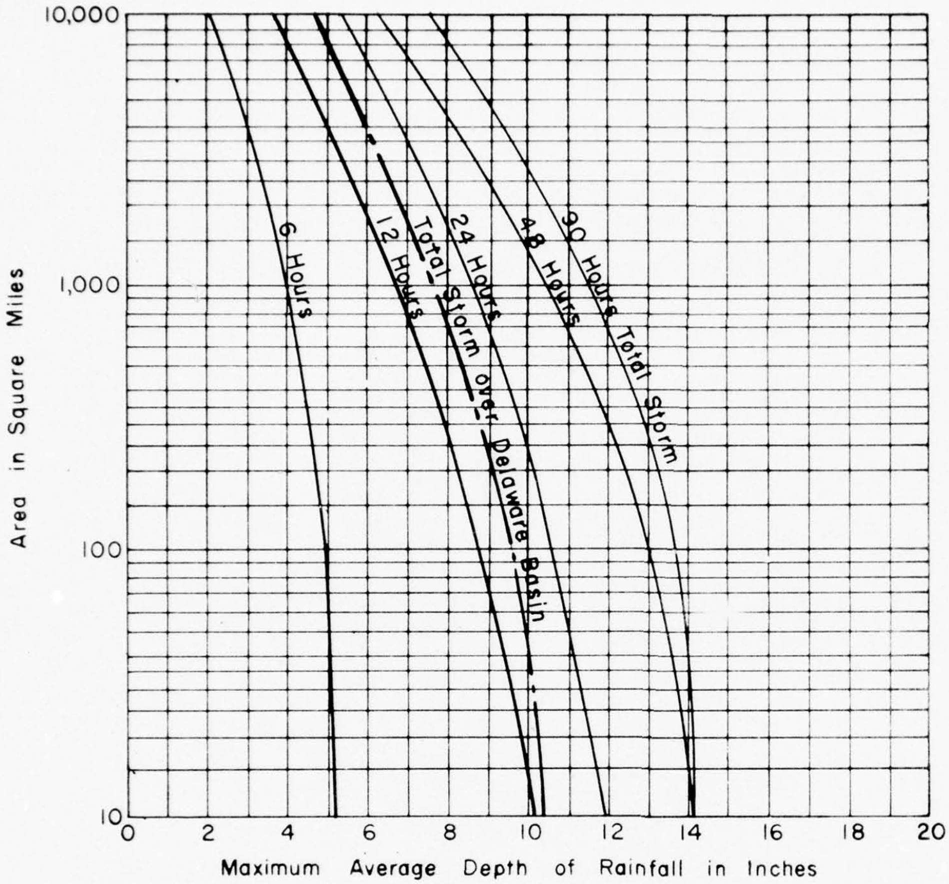
U. S. ARMY


NEW YORK
PENNSYLVANIA
MASS
CONN
JERVIS
NEW YORK
CONN
NEW YORK CITY
LONG ISLAND
N
HARRISBURG
READING
CAMDEN
WILMINGTON
ATLANTIC CITY
DOVER
DELAWARE
MARYLAND
Approx. Scale
1: 2,000,000

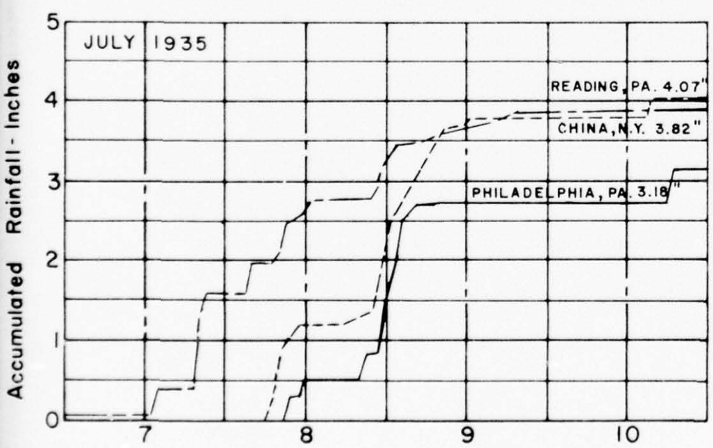

10,000
1,000
100
10
0
Area in Square Miles


JULY 1935
5
4
3
2
1
0
7
Accumulated Rainfall - Inches
MASS C


Auburn
Port Clinton
Berne
Little
Lanark
Friedensville
Milford
Frenchtown
Pipersville
Point Pleasant
Lumberville
Stockton
Lambertville
Reading



MAXIMUM DEPTH-AREA-DURATION CURVES



MASS CURVES OF RAINFALL

Storm Center
Pottsville, Pa.

REVIEW REPORT

DELAWARE RIVER BASIN

ISOHYETAL MAP

STORM OF 7-9 JULY 1935

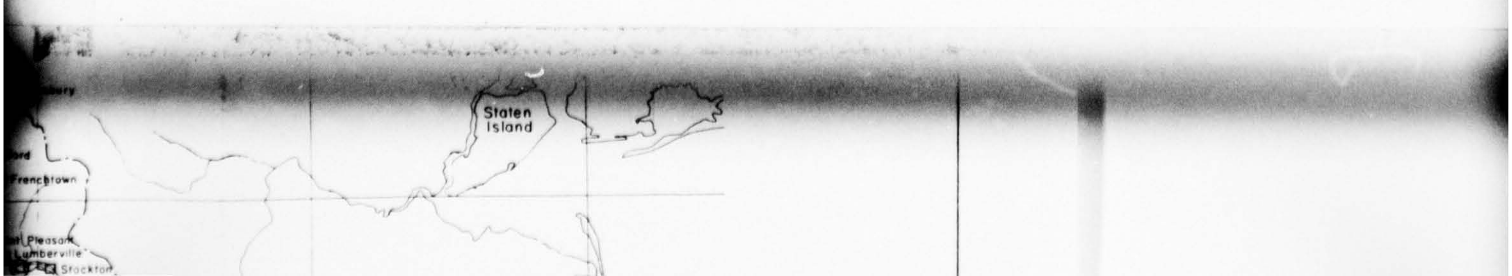
In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

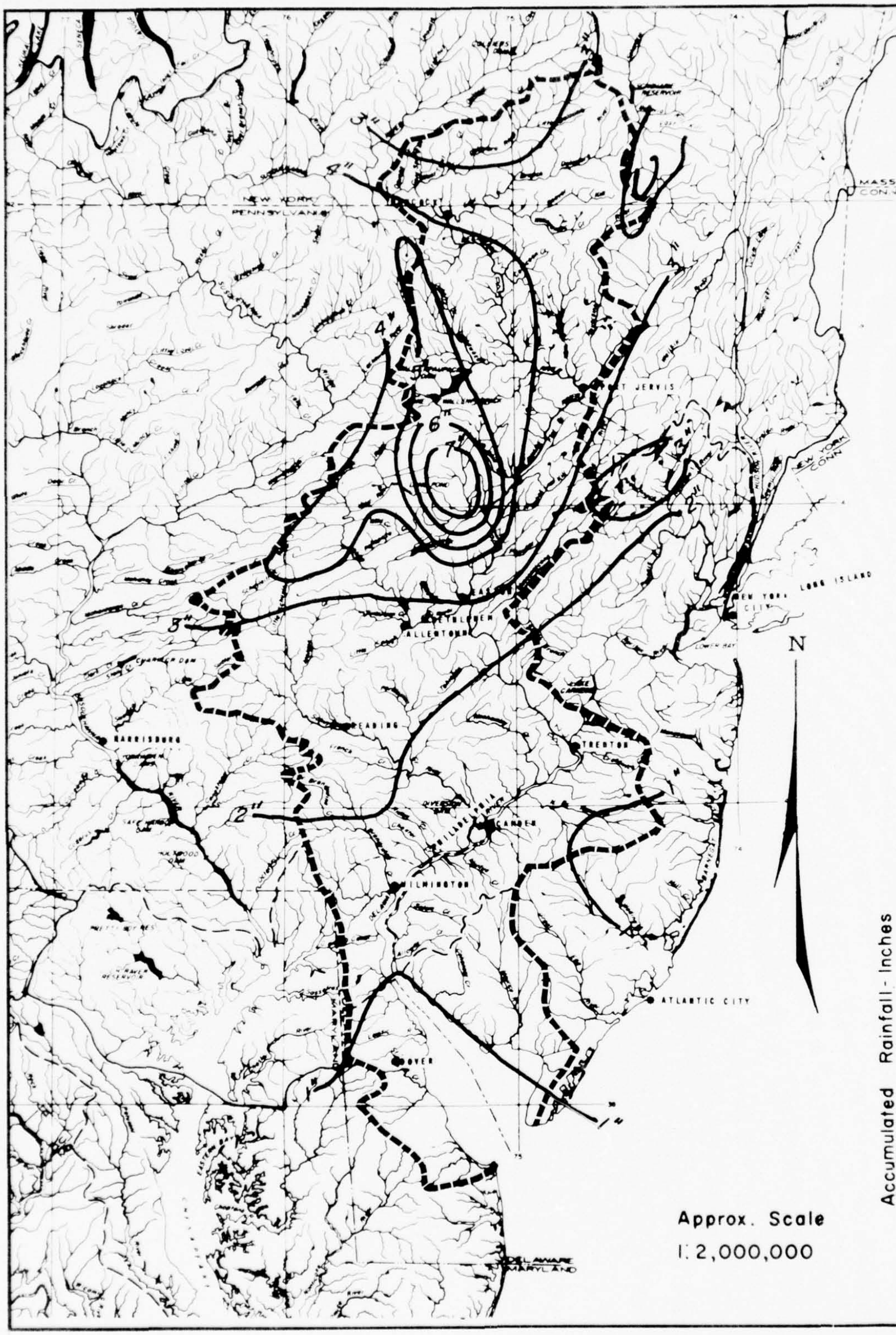
Scales as Shown
Philadelphia District
NOVEMBER 1958

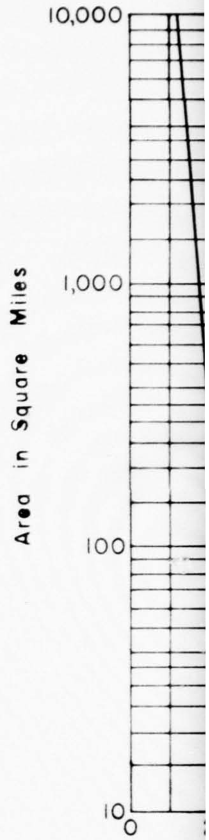
Drawer No. 228

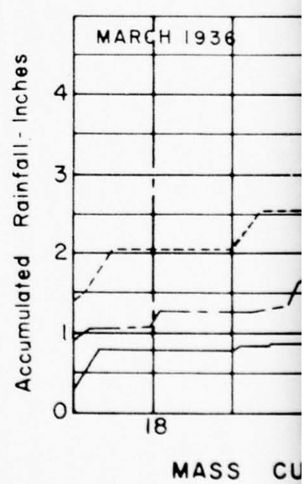
File No. **28086**

PLATE No. 11



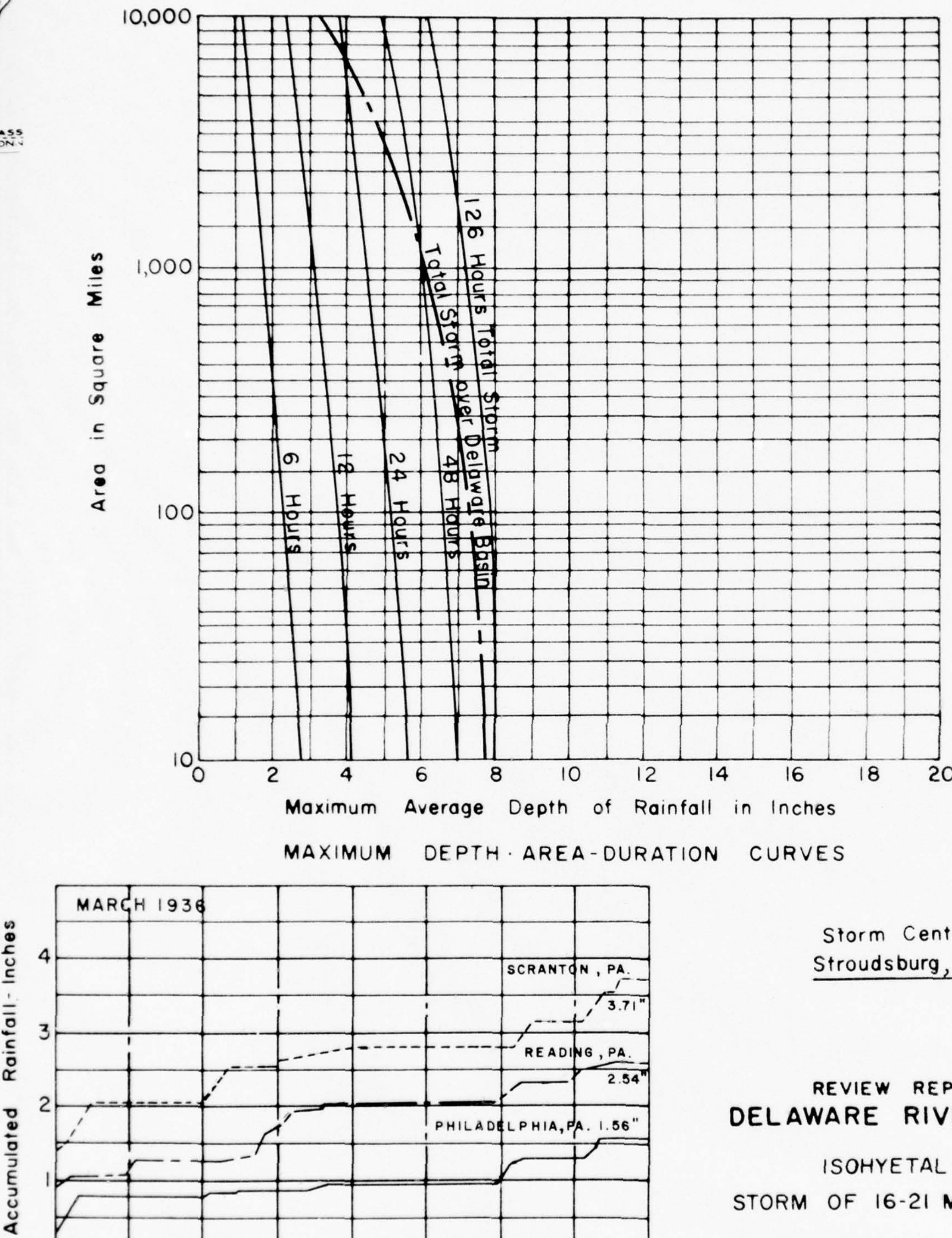






CORPS OF ENGINEERS

U.S. ARMY



MAXIMUM DEPTH - AREA - DURATION CURVES

MASS CURVES OF RAINFALL

Storm Center
Stroudsburg, Pa.

REVIEW REPORT

DELAWARE RIVER BASIN

ISOHYETAL MAP

STORM OF 16-21 MARCH 1936

In 1 Sheet
Corps of Engineers
Philadelphia, Pa

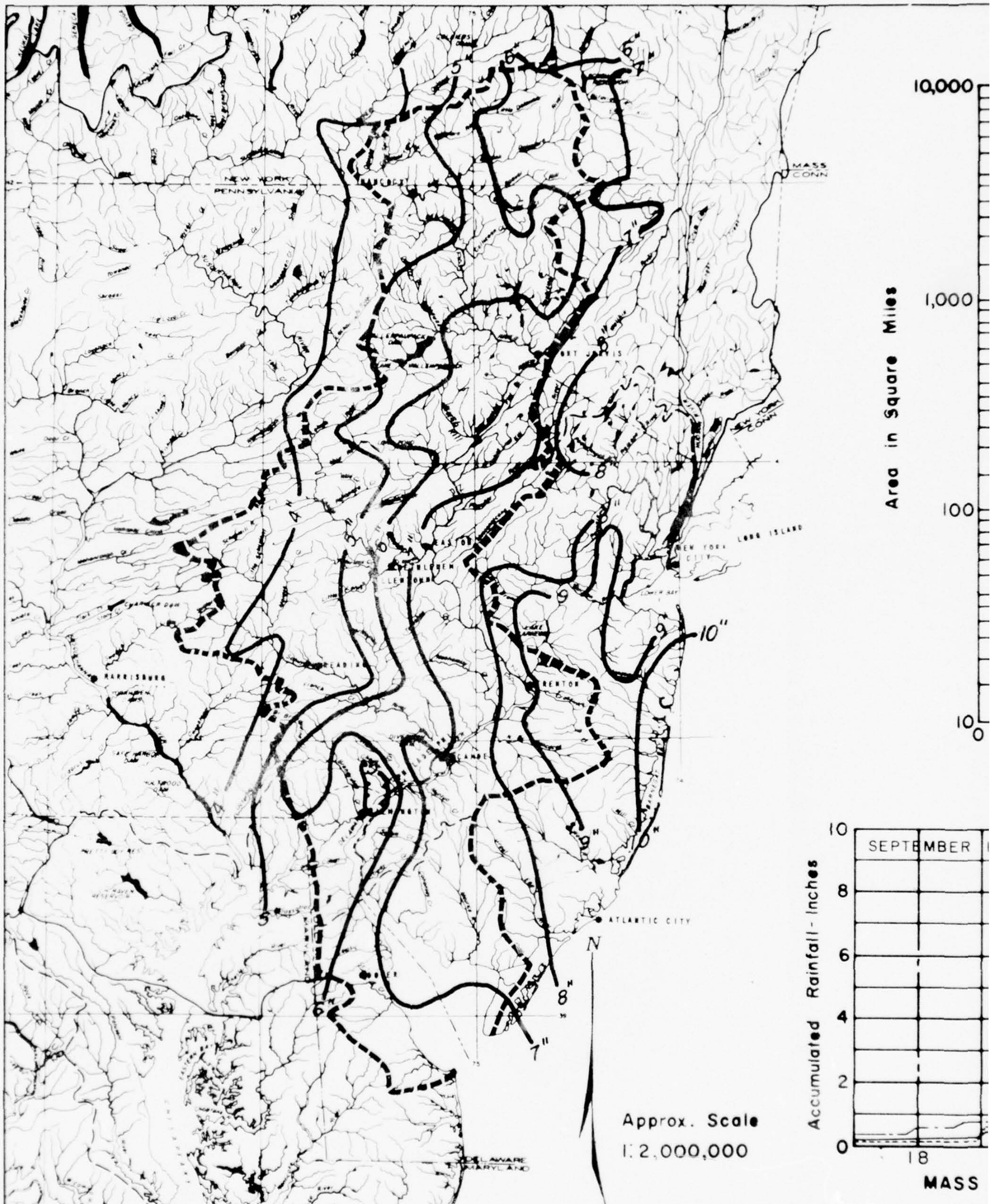
Scales as Shown
Philadelphia District
NOVEMBER 1958

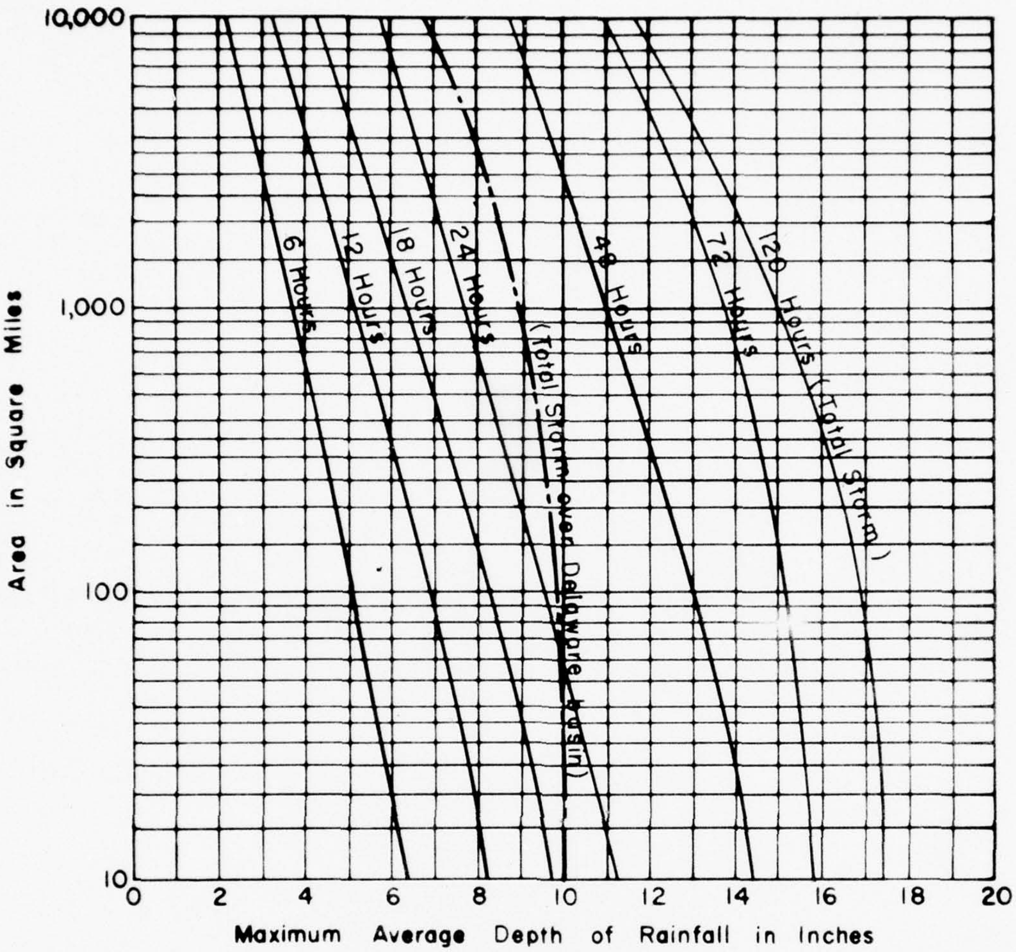
Drawer No. 228

File No. 28087

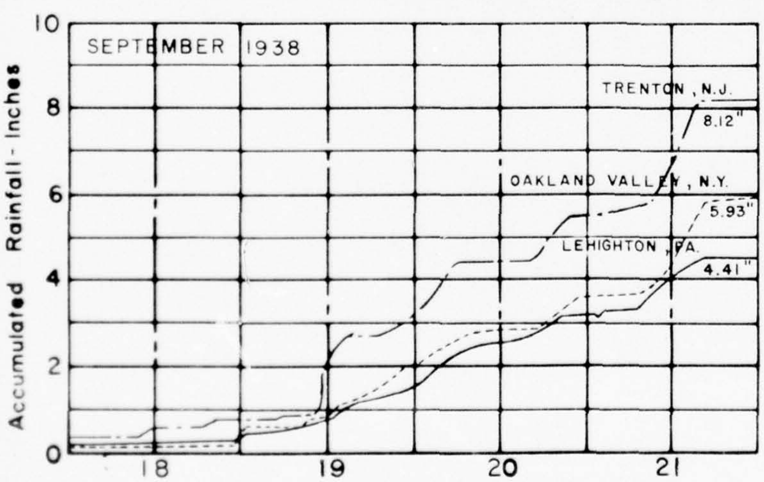
PLATE No. 12

CORPS OF ENGINEERS





MAXIMUM DEPTH-AREA-DURATION CURVES



MASS CURVES OF RAINFALL

Storm Center
Buck, Conn.

REVIEW REPORT

DELAWARE RIVER BASIN

ISOHYETAL MAP

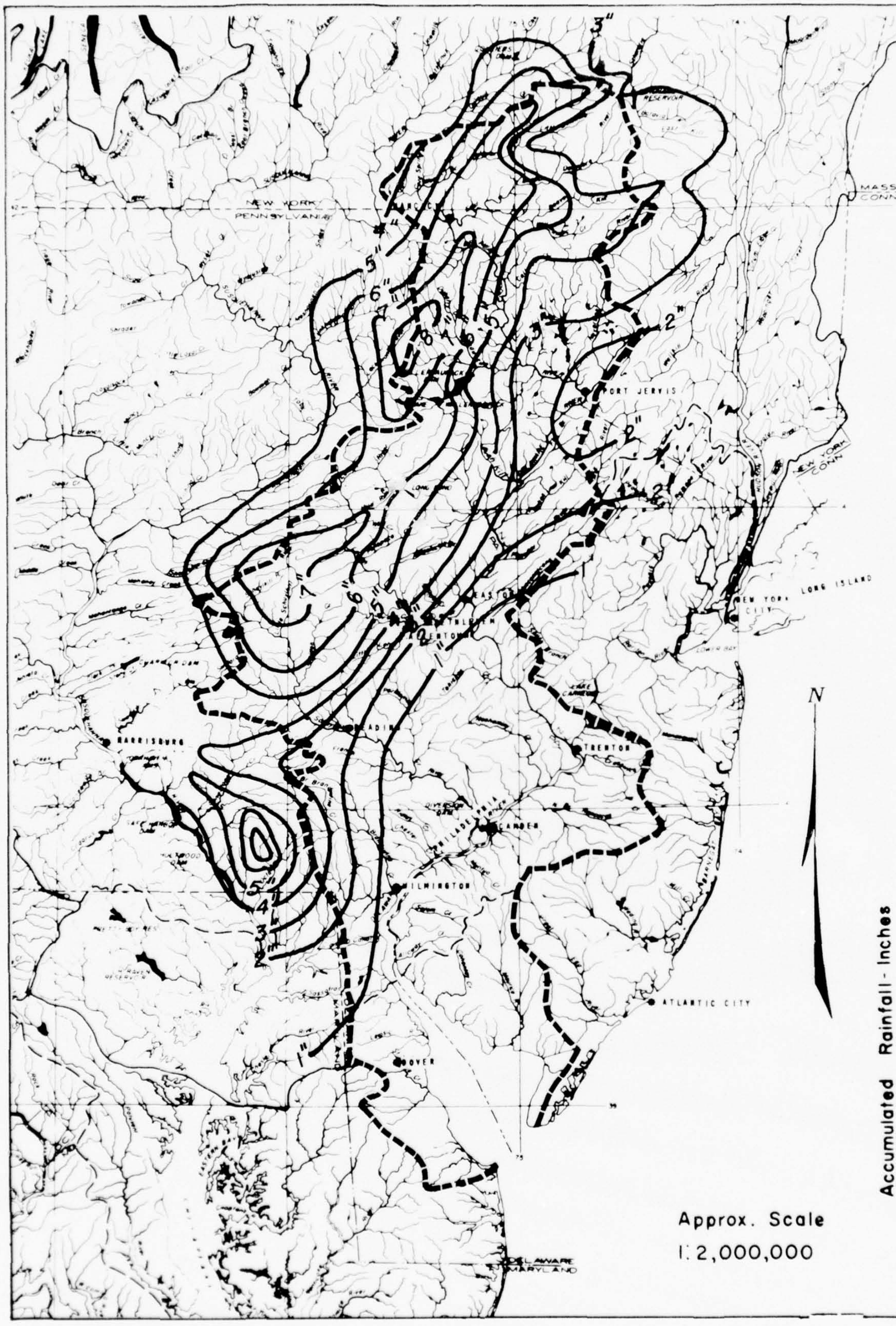
STORM OF 17-21 SEPT. 1938

In 1 Sheet
Corps of Engineers
Philadelphia, Pa

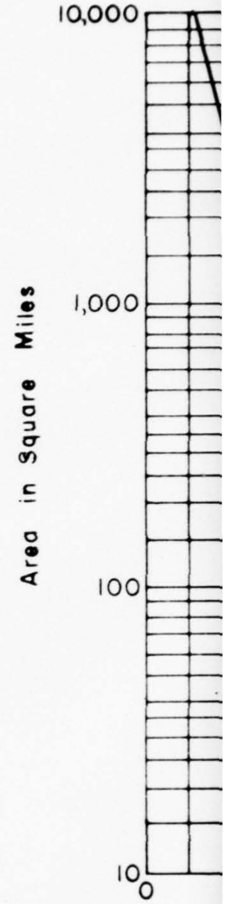
Scales as Shown
Philadelphia District
NOVEMBER 1958

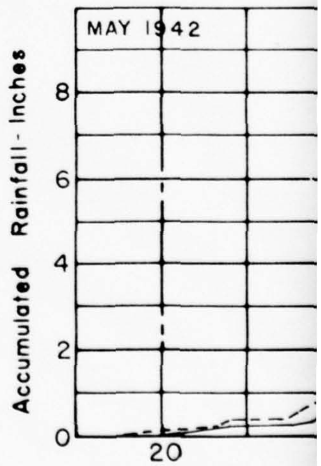
Drawer No 228

File No 28088



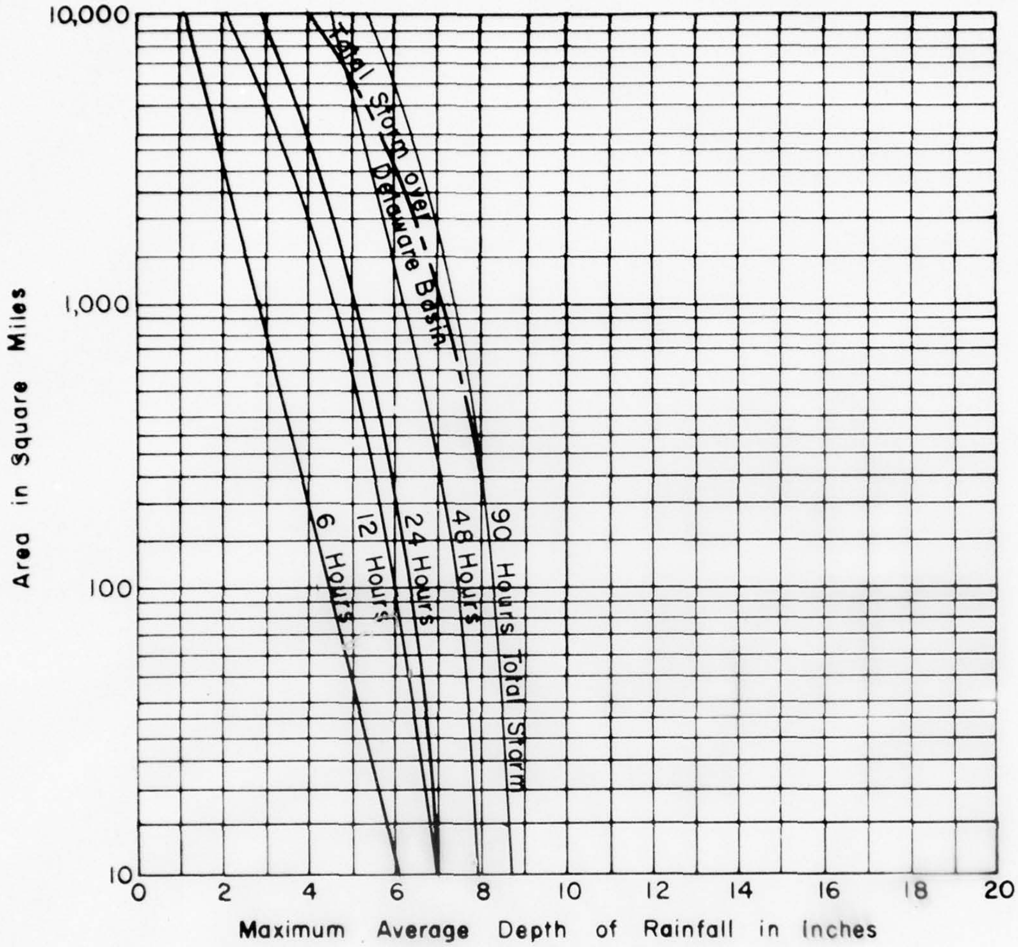
Approx. Scale
1: 2,000,000



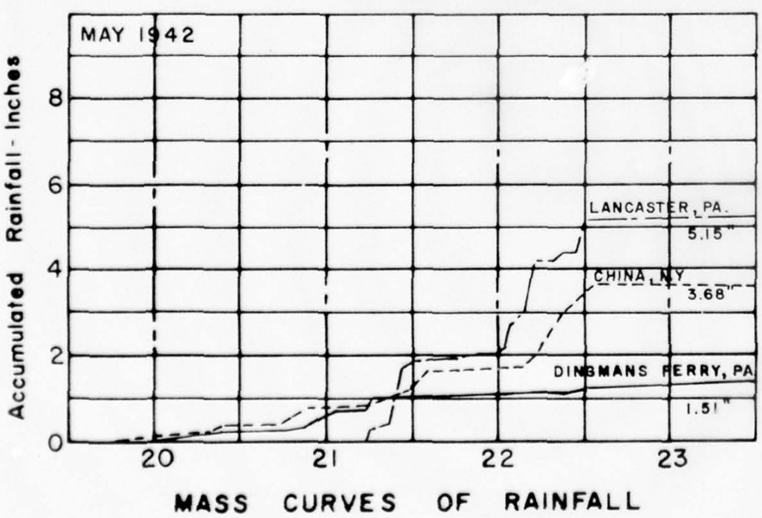


MASS CU

U.S. ARMY



MAXIMUM DEPTH · AREA - DURATION CURVES



MASS CURVES OF RAINFALL

Storm Center
Honesdale, Pa.

REVIEW REPORT
DELAWARE RIVER BASIN

ISOHYETAL MAP
STORM OF 19-23 MAY 1942

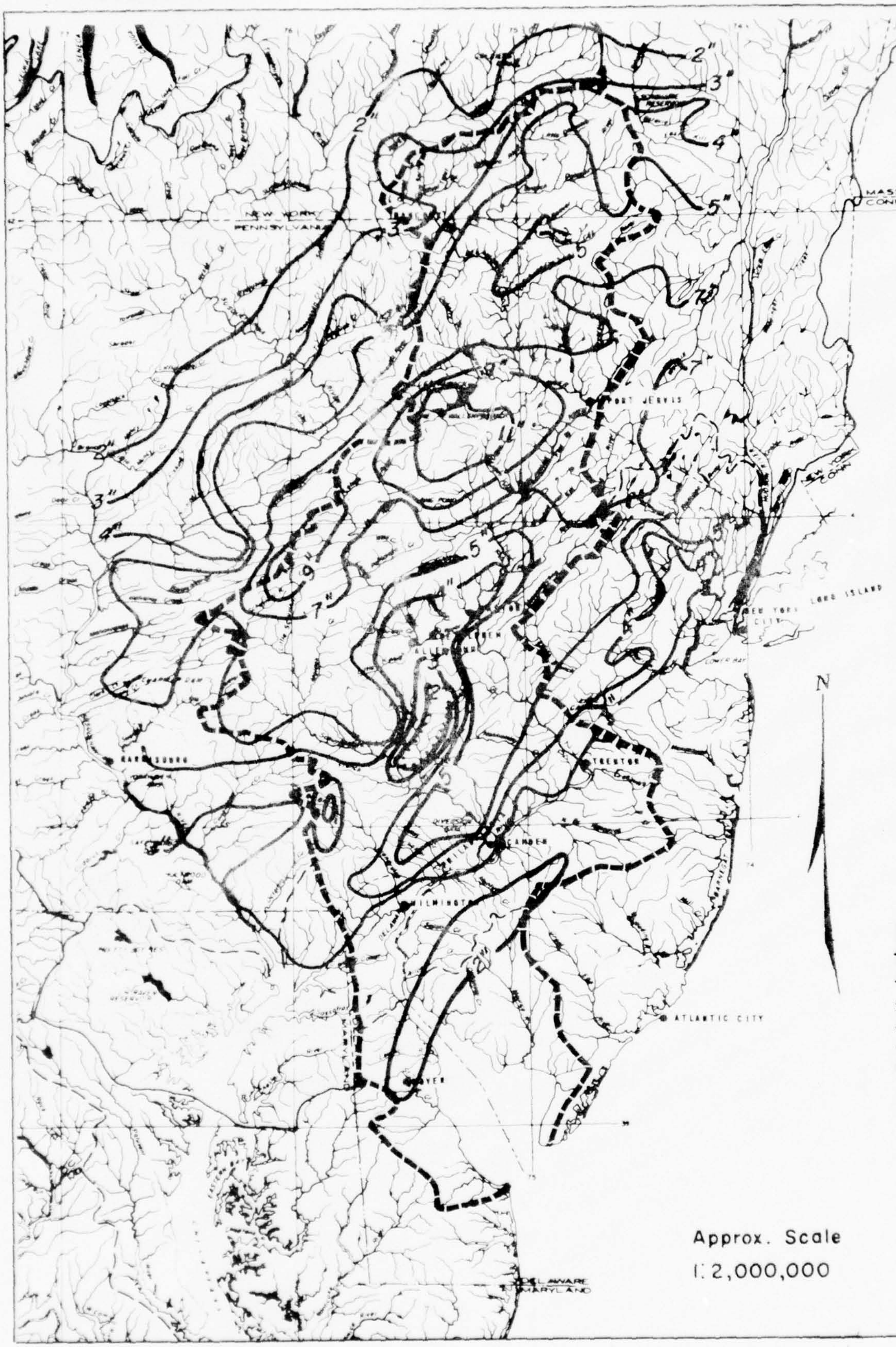
In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

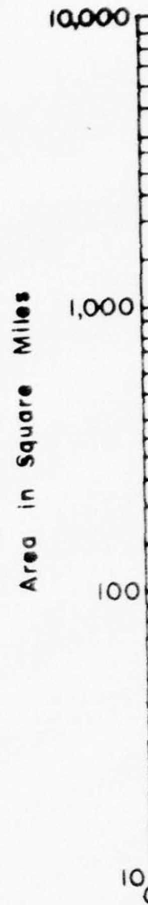
Scales as Shown
Philadelphia District
NOVEMBER 1958

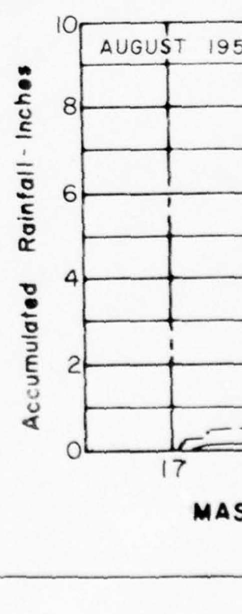
Drawer No 228

File No. 28089

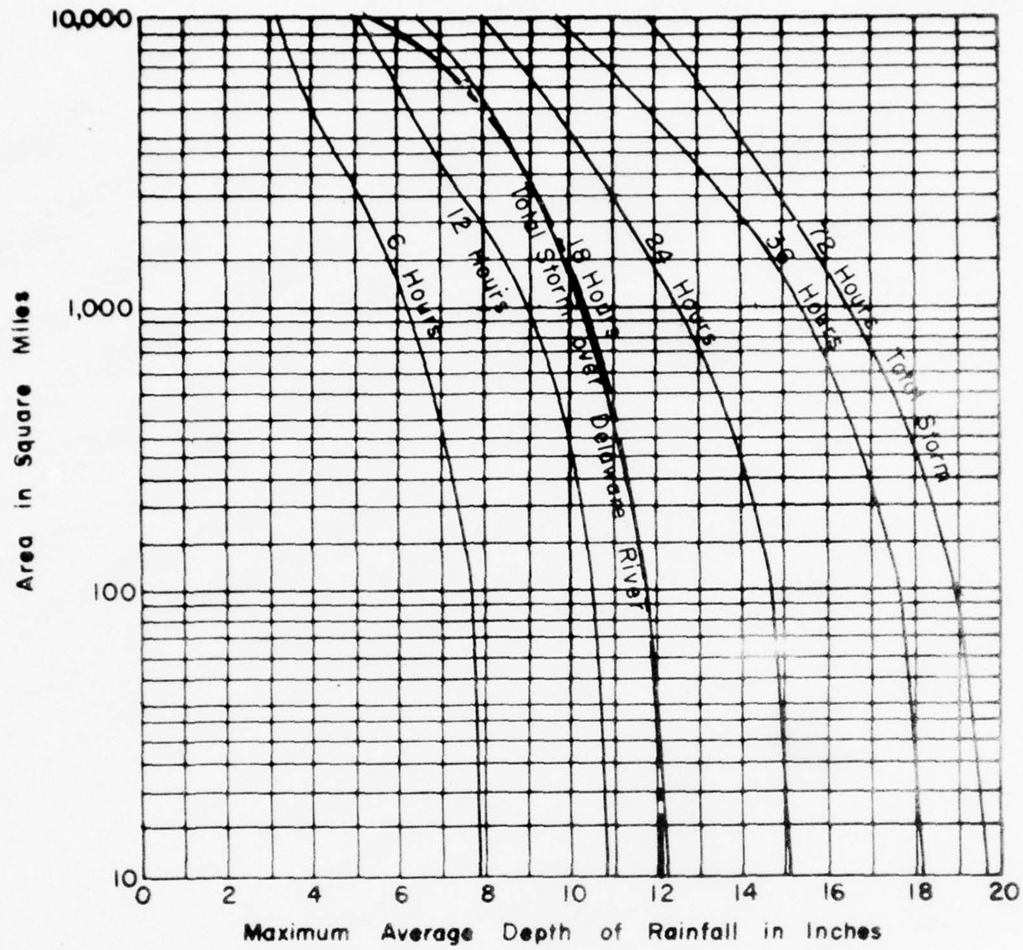
PLATE No. 14


NEW YORK
PENNSYLVANIA
MASS
CONN
PORT JERVIS
NEW YORK
CITY
LONG ISLAND
HARRISBURG
TRENTON
CAMDEN
ATLANTIC CITY
DELAWARE
MARYLAND
N
Approx. Scale
1:2,000,000

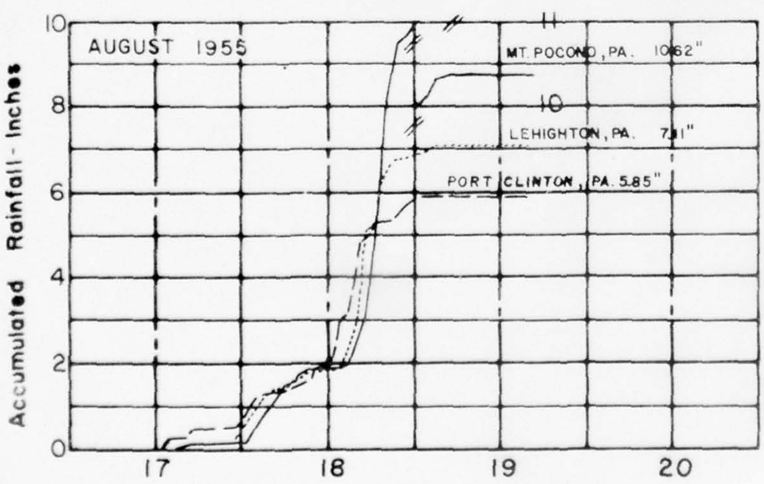

10,000
1,000
100
10
0
Area in Square Miles


AUGUST 1955
10
8
6
4
2
0
17
Accumulated Rainfall - Inches
MAS

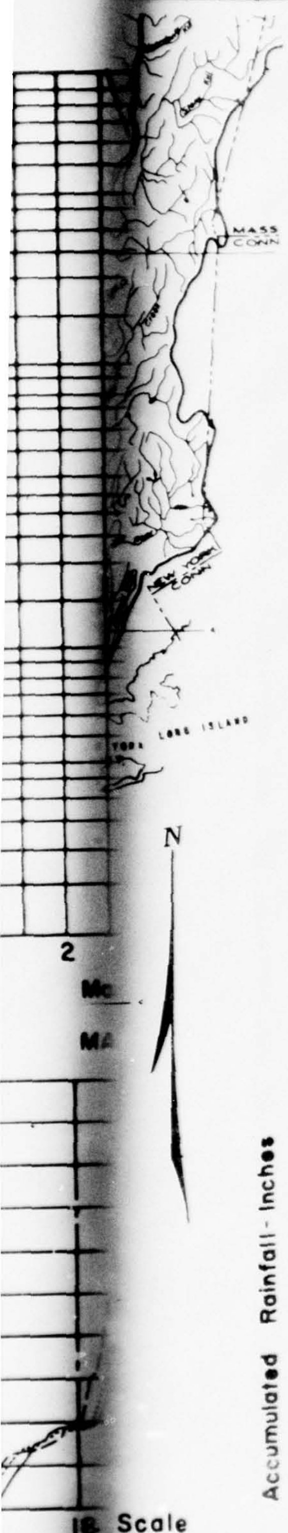
U.S. ARMY



MAXIMUM DEPTH-AREA-DURATION CURVES



MASS CURVES OF RAINFALL



Storm Center
Westfield Water Dept., Mass.

REVIEW REPORT

DELAWARE RIVER BASIN

ISOHYETAL MAP
STORM OF 17-19 AUGUST 1955

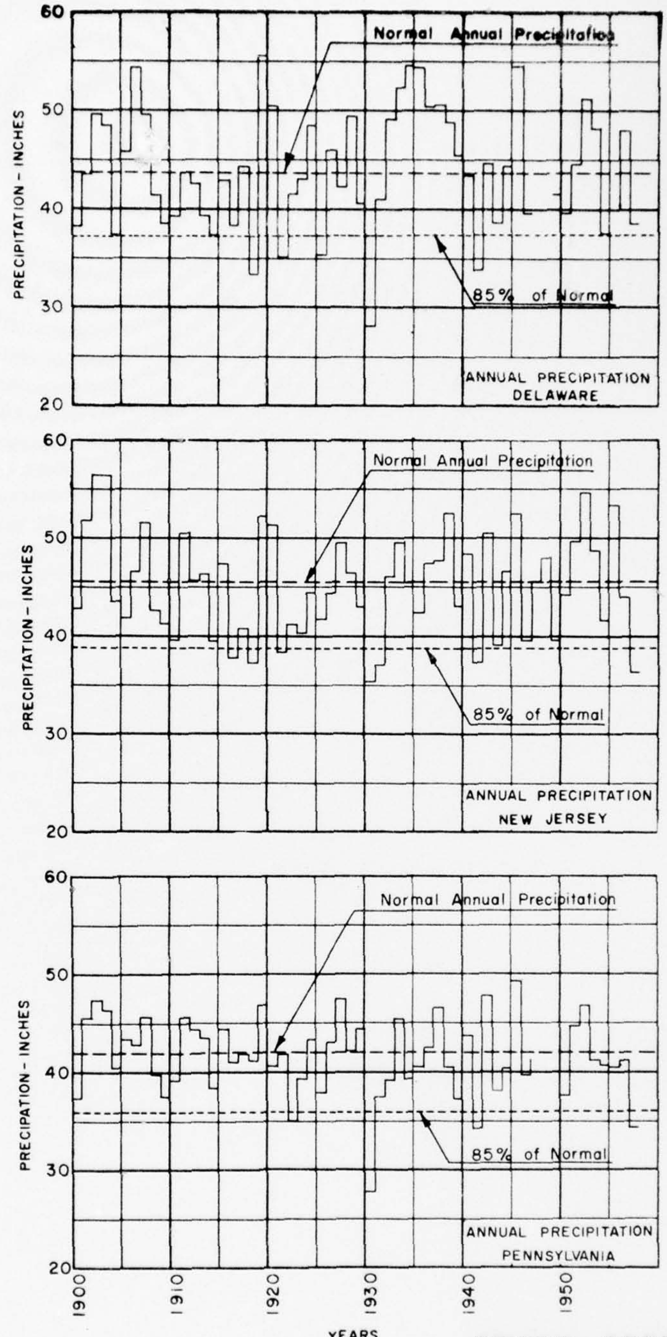
In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scales as Shown
Philadelphia District
NOVEMBER 1958

Drawer No. 228

File No. 28090

CORPS OF ENGINEERS U.S. ARMY



REVIEW REPORT

DELAWARE RIVER BASIN

ANNUAL PRECIPITATION

NEW JERSEY, DELAWARE

PENNSYLVANIA

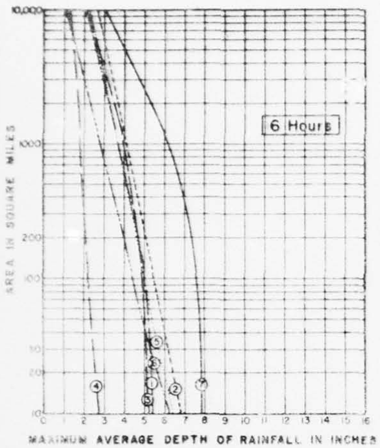
In 1 Sheet — Scales as Shown

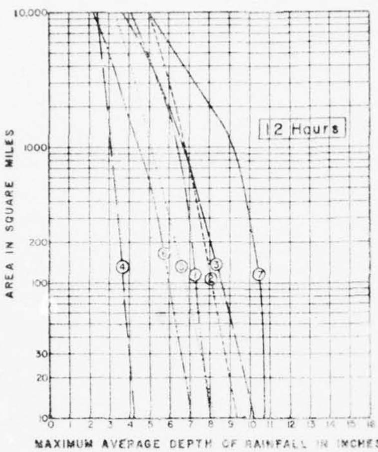
Corps of Engineers — Philadelphia District

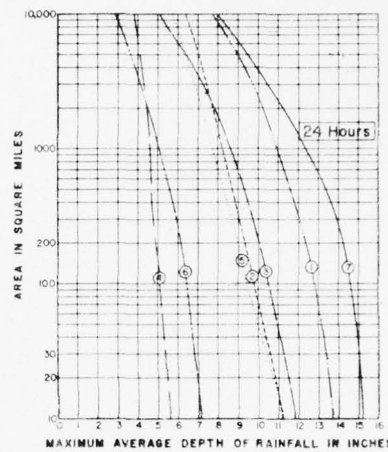
Philadelphia, Pa. — November 1958

Drawer No. 228 — File No. 28091

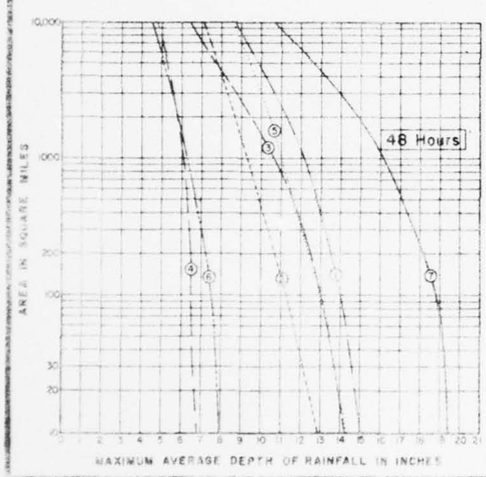
PLATE NO. 16

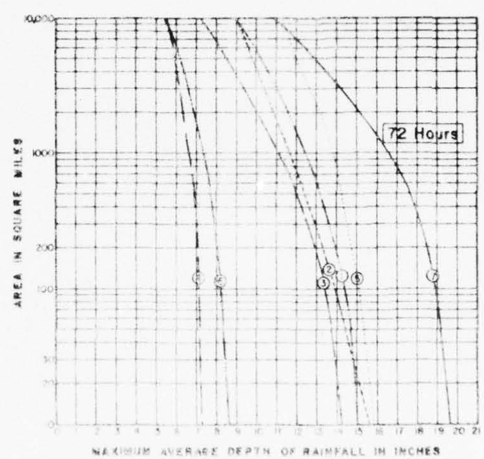






LOCATION MAP





LEGEND

NO.	SYMBOL	CODE NO.	DATE OF STORM	LOCATION OF MAX. CENTER
1	— - —	G.L. 4-9	7-11 October 1903	Paterson, N.J.
2	--------	N.A. 1-24	20-24 August 1933	Peekamoose, N.Y.
3	— —	N.A. 1-27	6-10 July 1935	Hector, N.Y. & Pottsville Pa.
4	— —	S.A. 1-27	16-21 March 1936	Romney, W. Va.
5	....	N.A. 2-2	17-22 Sept. 1938	Buck, Conn.
6	—-—-	N.A. 2-5	19-23 May 1942	Mahanoy City, Pa.
7	———	N.A. 2-25A	17-20 August 1955	Westfield, Mass.

REVIEW REPORT

DELAWARE RIVER BASIN

STORM RAINFALL

MAXIMUM DEPTH-AREA-DURATION RELATIONS

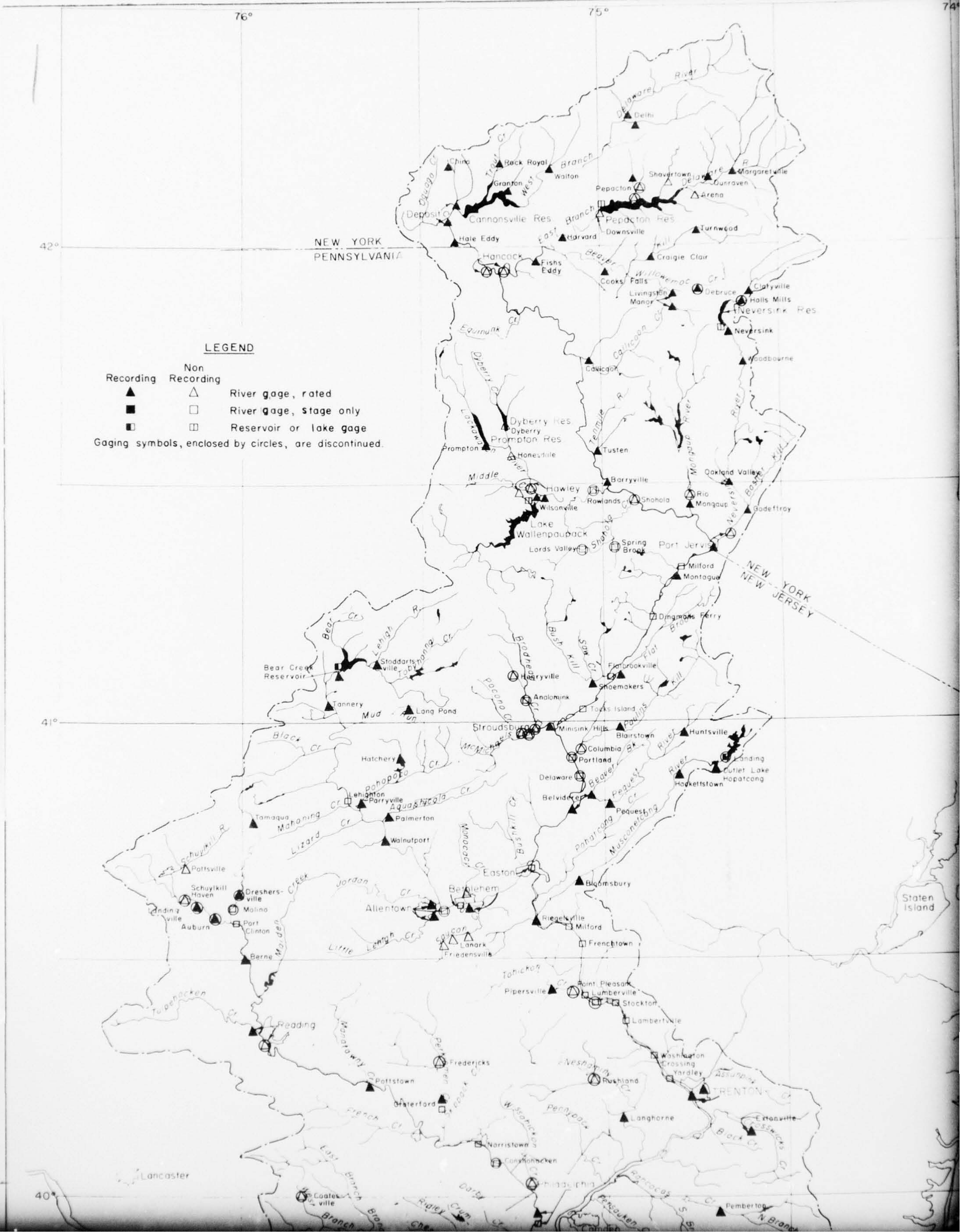
In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scales as Shown
Philadelphia District
15 July 58

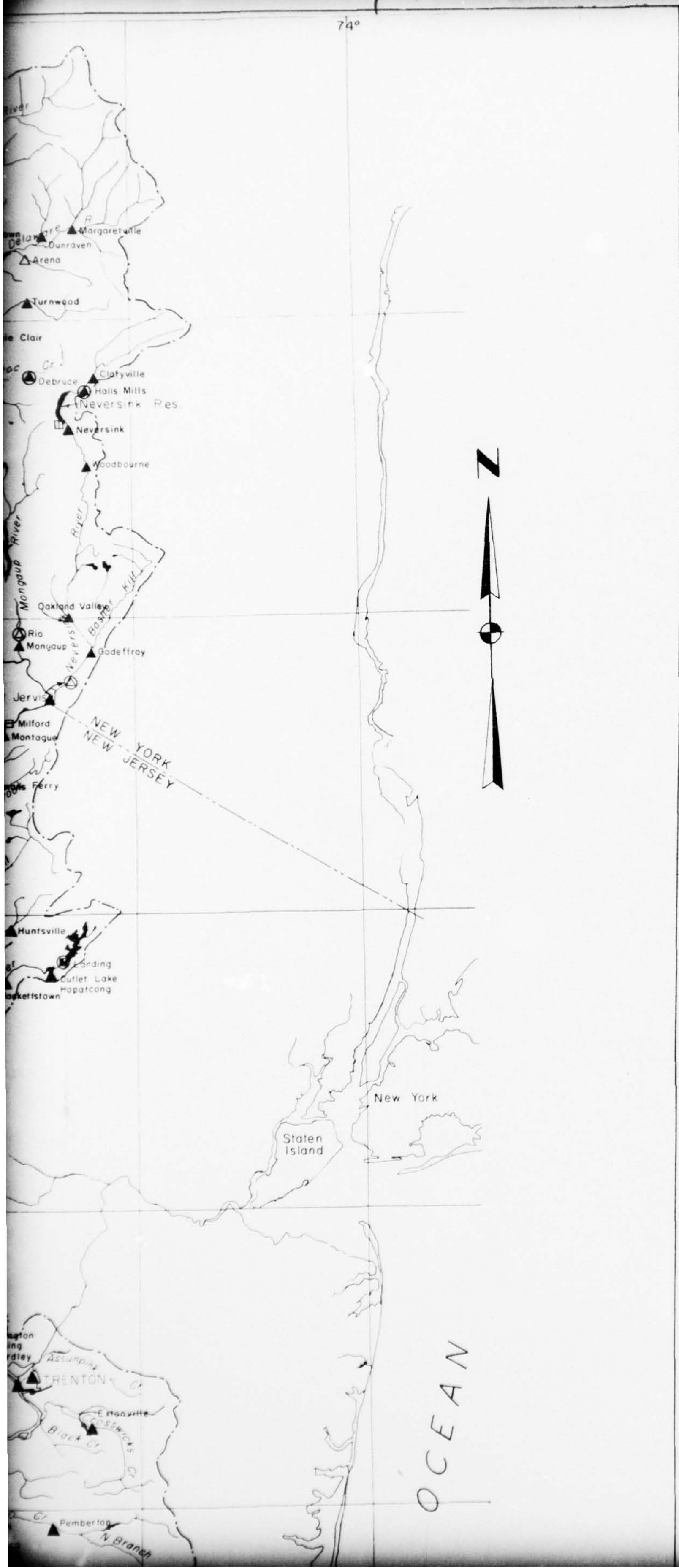
Drawer No. 228

File No. 28092

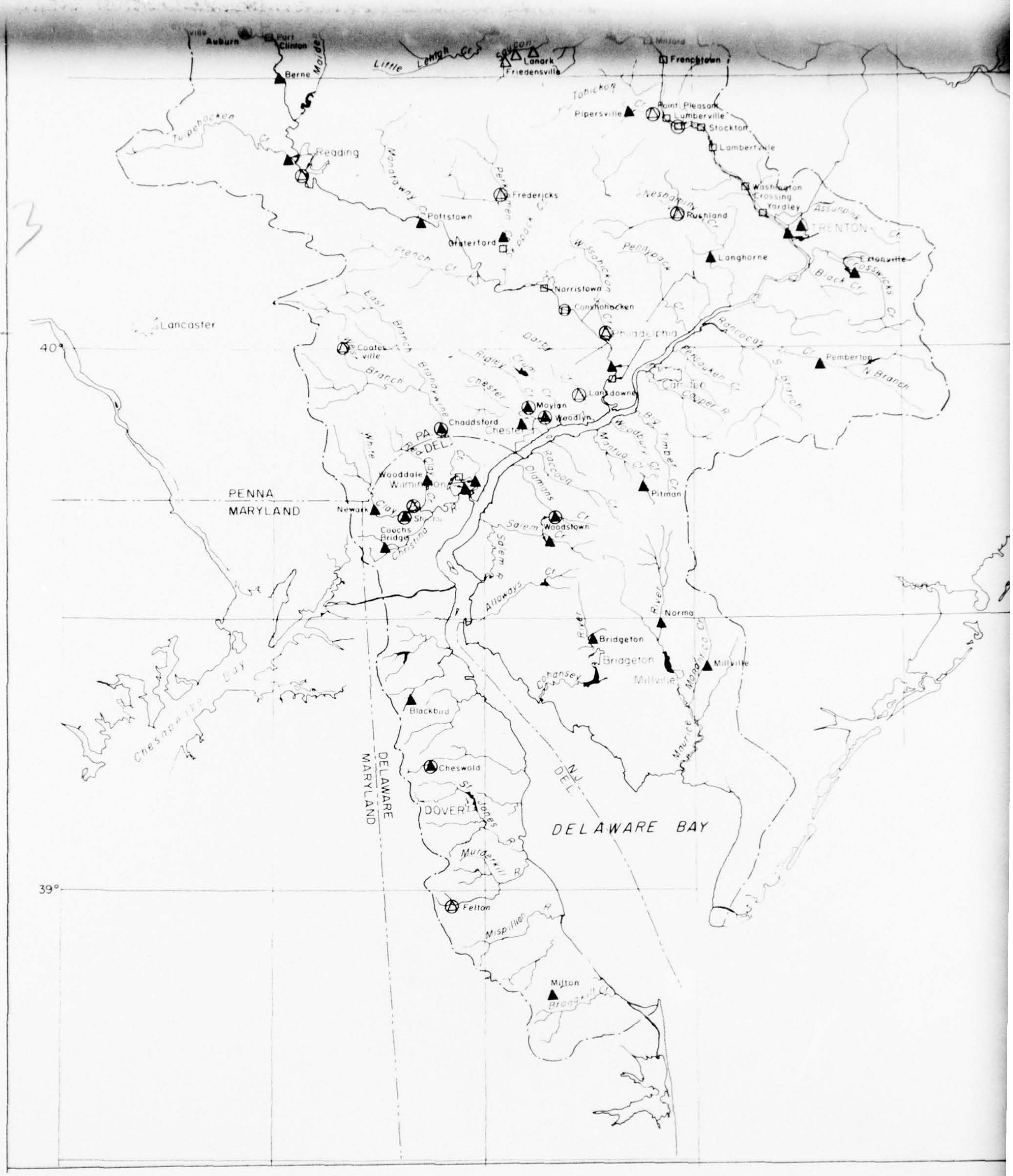
CORPS OF ENGINEERS



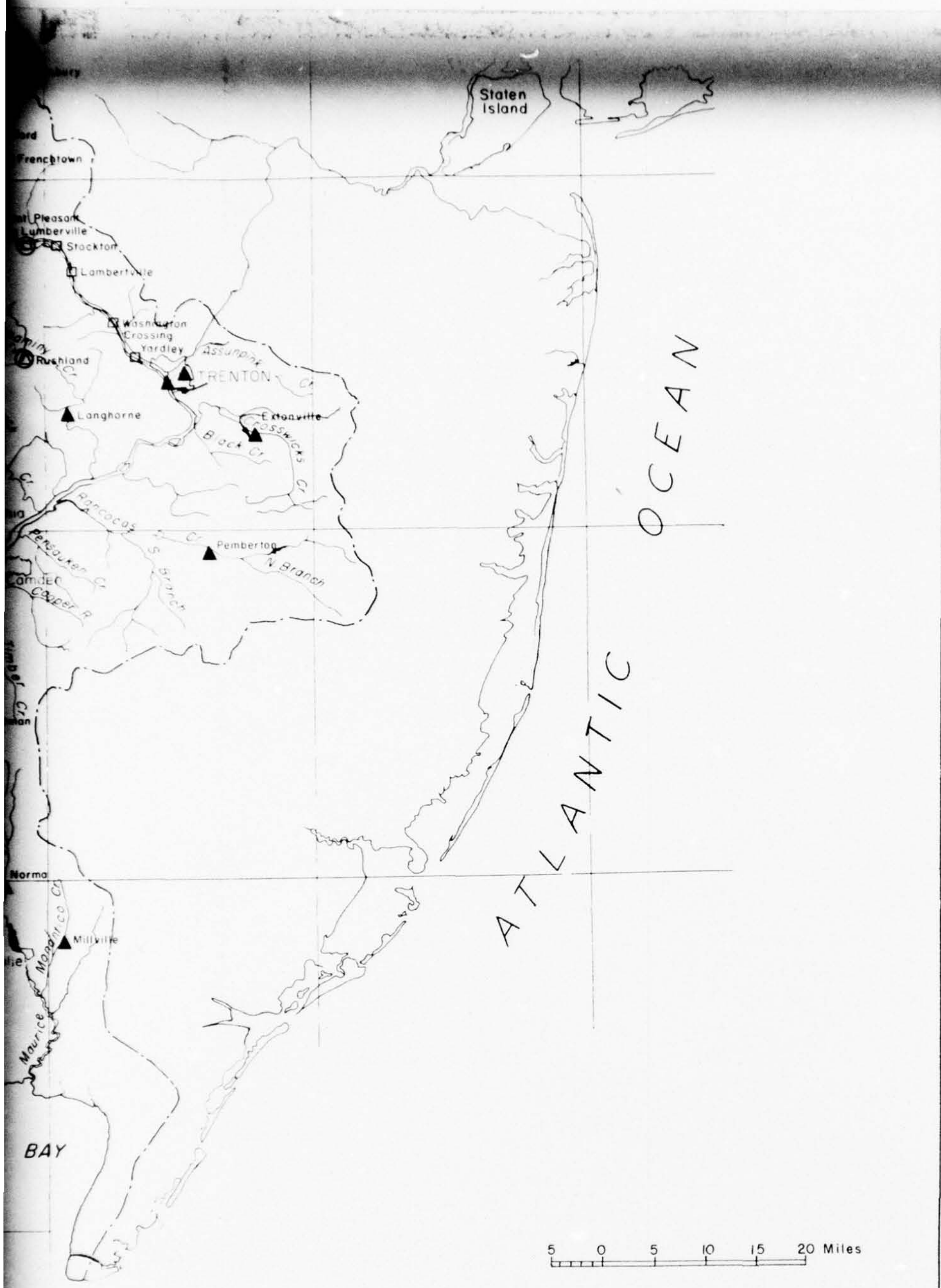
U. S. ARMY


74°
Margaretville
Dunraven
Arena
Turnwood
Claryville
Debruce
Halls Mills
Neversink Res.
Neversink
Woodbourne
Mongaup River
Oakland Valley
Rio
Mongaup
Godeffroy
Basher Kill
Milford
Montague
NEW YORK
NEW JERSEY
Huntsville
Landing
Outlet Lake Hopatcong
New York
Staten Island
TRENTON
Assunpink Cr.
Extonville
Crosswicks Cr.
Black Cr.
Pemberton
N. Branch
OCEAN
N

3



Auburn
Port Clinton
Berne
Little Lehigh Cr
Lanark
Friedensville
Frenchtown
Milford
Tohickon
Pipersville
Point Pleasant
Lumberville
Stockton
Lambertville
Tulpehocken
Reading
Manatawny Cr
Perkiomen
Fredericks
Washington Crossing
Yardley
Assunpink
TRENTON
Neshaminy Cr
Rushland
Pottstown
Graterford
Pennypack
Langhorne
Crosswicks Cr
Extonville
French Cr
Black Cr
Norristown
W. Branch
Conshohocken
Lancaster
East Branch
Philadelphia
Rancocas Cr
Pemberton
N Branch
S. Branch
40°
Coatesville
Branch
Brandywine
Darby
Ridley
Crum
Chester
Lansdowne
Camden
Cooper R
Moylan
Woodlyn
Chadds Ford
Chester
PA
DEL
White Clay Cr
Woodbury Cr
Timber Cr
Mantua Cr
Raccoon
Oldmans
Woodstown
Salem Cr
Pitman
Wooddale
Wilmington
PENNA
MARYLAND
Newark
Stanton
Christina R
Coochs Bridge
Salem R
Alloways Cr
Norma
Bridgeton
Millville
Maurice
Cohansey
Chesapeake Bay
Blackbird
DELAWARE
MARYLAND
NJ
DEL
Cheswold
St Jones R
DOVER
DELAWARE BAY
Murderkill R
39°
Felton
Mispillion R
Milton
Broadkill Cr



4

REVIEW REPORT

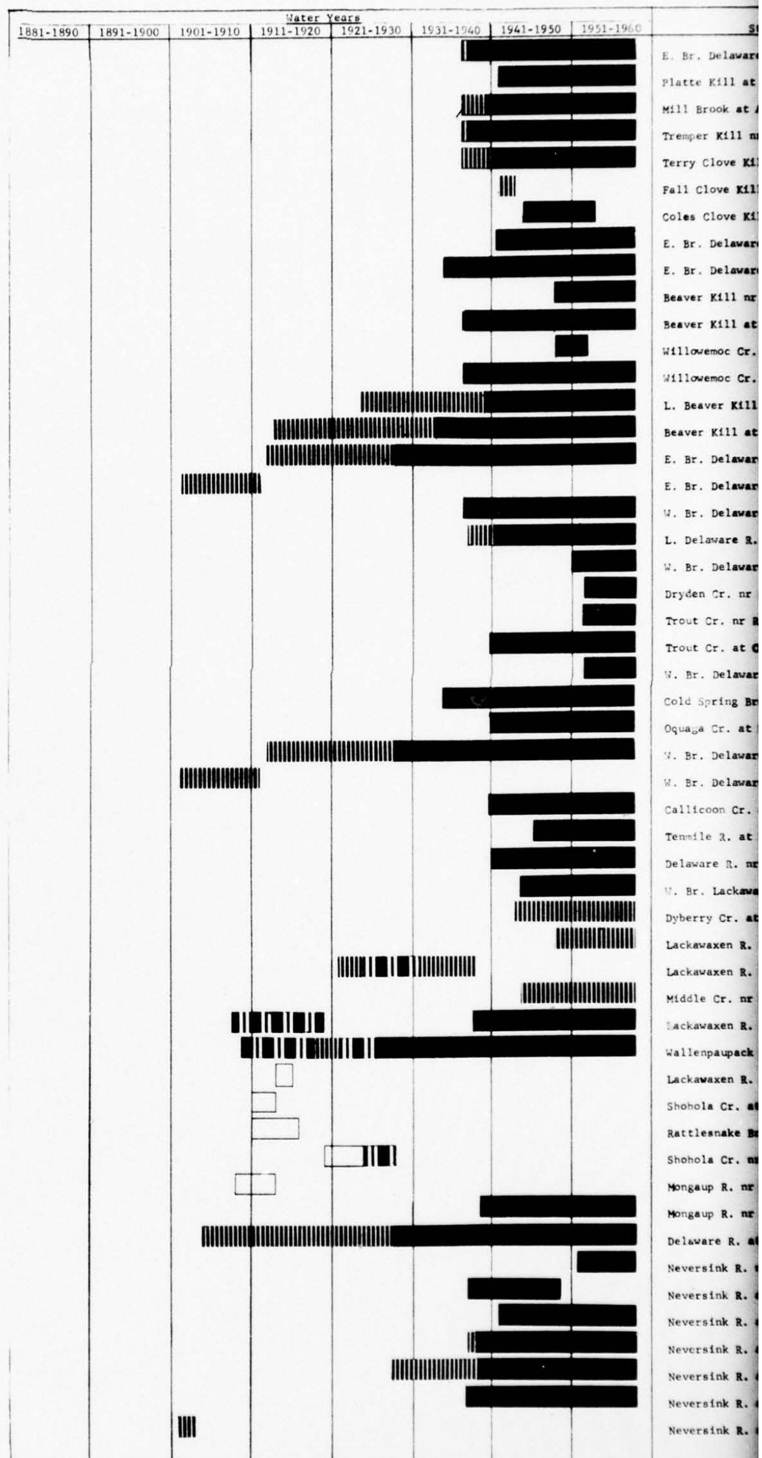
DELAWARE RIVER BASIN

STREAM GAGING STATIONS

In 1 Sheet	Scale as Shown
Corps of Engineers	Philadelphia District
Philadelphia, Pa	23 Oct. 1959
Drawer No. 228	File No. 28093

PLATE NO. 18

CORPS OF ENGINEERS



2-1

1931-1940 | 1941-1950 | 1951-1960 | Station

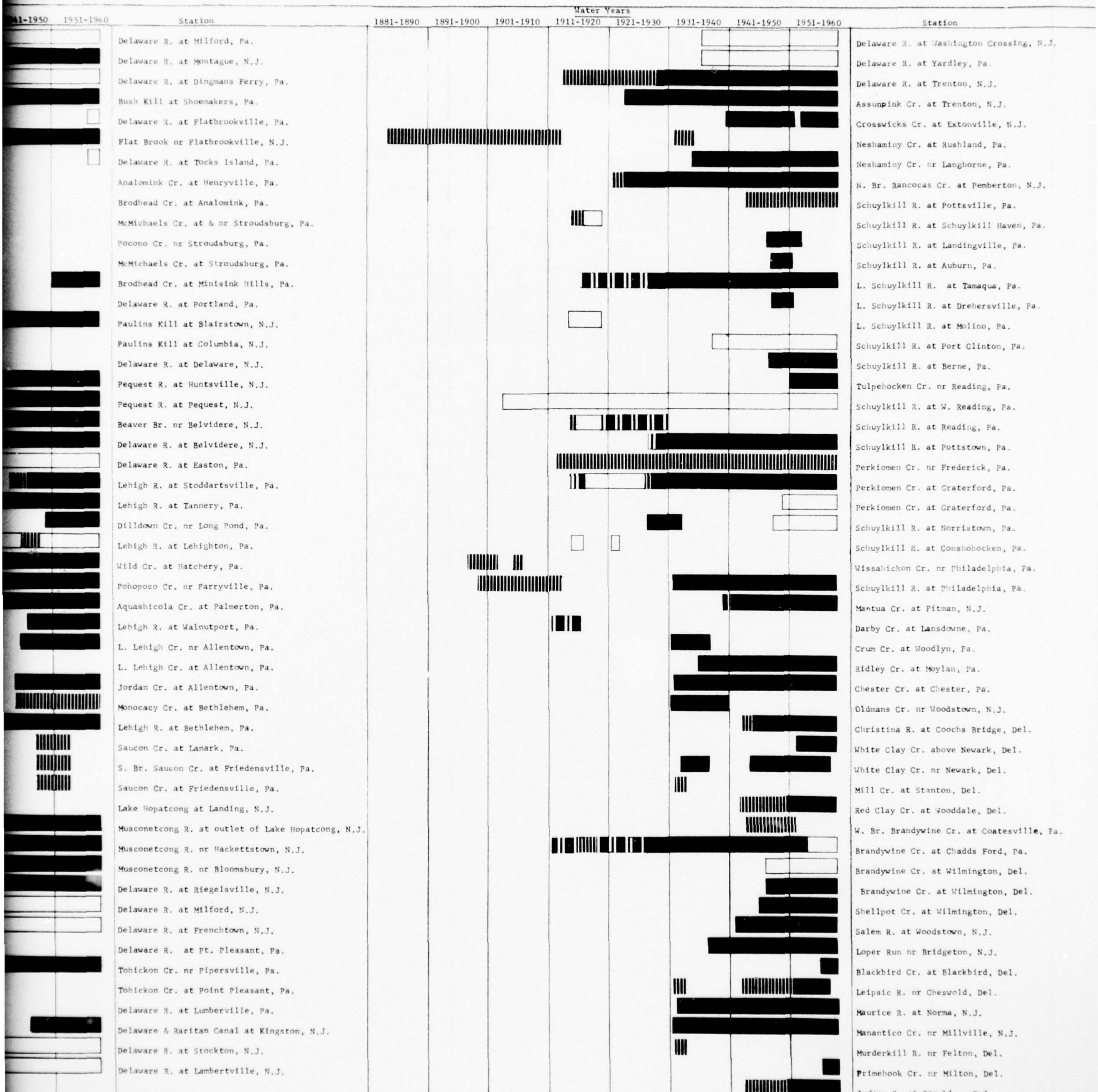
- E. Br. Delaware R. at Margaretville, N.Y.
- Platte Kill at Dunraven, N.Y.
- Mill Brook at Arena, N.Y.
- Tremper Kill nr Shavertown, N.Y.
- Terry Clove Kill nr Pepacton, N.Y.
- Fall Clove Kill nr Pepacton, N.Y.
- Coles Clove Kill nr Pepacton, N.Y.
- E. Br. Delaware R. at Downsville, N.Y.
- E. Br. Delaware R. at Harvard, N.Y.
- Beaver Kill nr Turnwood, N.Y.
- Beaver Kill at Craigie Clair, N.Y.
- Willowemoc Cr. at Debruce, N.Y.
- Willowemoc Cr. nr Livingston Manor, N.Y.
- L. Beaver Kill nr Livingston Manor, N.Y.
- Beaver Kill at Cooks Falls, N.Y.
- E. Br. Delaware R. at Fishs Eddy, N.Y.
- E. Br. Delaware R. at Hancock, N.Y.
- W. Br. Delaware R. at Delhi, N.Y.
- L. Delaware R. nr Delhi, N.Y.
- W. Br. Delaware R. at Walton, N.Y.
- Dryden Cr. nr Granton, N.Y.
- Trout Cr. nr Rock Royal, N.Y.
- Trout Cr. at Cannonsville, N.Y.
- W. Br. Delaware R. at Stilesville, N.Y.
- Cold Spring Brook at China, N.Y.
- Oquaga Cr. at Deposit, N.Y.
- W. Br. Delaware R. at Hale Eddy, N.Y.
- W. Br. Delaware R. at Hancock, N.Y.
- Callicoon Cr. at Callicoon, N.Y.
- Tenmile R. at Tusten, N.Y.
- Delaware R. nr Barryville, N.Y.
- W. Br. Lackawaxen R. at Prompton, Pa.
- Dyberry Cr. at Dyberry, Pa.
- Lackawaxen R. nr Honesdale, Pa.
- Lackawaxen R. at W. Hawley, Pa.
- Middle Cr. nr Hawley, Pa.
- Lackawaxen R. at Hawley, Pa.
- Wallenpaupack Cr. at Wilsonville, Pa.
- Lackawaxen R. at Rowlands, Pa.
- Shohola Cr. at Lords Valley, Pa.
- Rattlesnake Br. at Spring Brook, Pa.
- Shohola Cr. nr Shohola, Pa.
- Mongaup R. nr Rio, N.Y.
- Mongaup R. nr Mongaup, N.Y.
- Delaware R. at Port Jervis, N.Y.
- Neversink R. nr Claryville, N.Y.
- Neversink R. at Halls Mills, nr Curry, N.Y.
- Neversink R. at Neversink, N.Y.
- Neversink R. at Woodbourne, N.Y.
- Neversink R. at Oakland Valley, N.Y.
- Neversink R. at Godeffroy, N.Y.
- Neversink R. at Port Jervis, N.Y.

Water Years

1881-1890 | 1891-1900 | 1901-1910 | 1911-1920 | 1921-1930 | 1931-1940 | 1941-1950 | 1951-1960 | Station

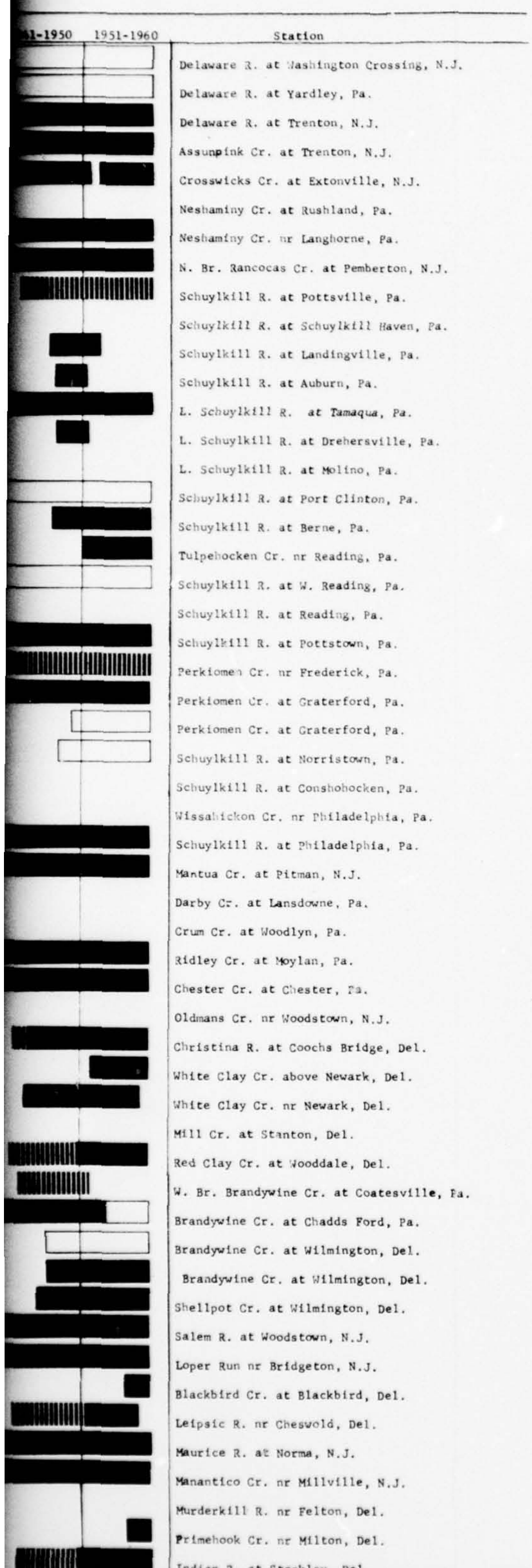
- Delaware R. at Milford, Pa.
- Delaware R. at Montague, N.J.
- Delaware R. at Dingmans Ferry, Pa.
- Bush Kill at Shoemakers, Pa.
- Delaware R. at Flatbrookville, Pa.
- Flat Brook nr Flatbrookville, N.J.
- Delaware R. at Tocks Island, Pa.
- Analomink Cr. at Henryville, Pa.
- Brodhead Cr. at Analomink, Pa.
- McMichaels Cr. at & nr Stroudsburg, Pa
- Pocono Cr. nr Stroudsburg, Pa.
- McMichaels Cr. at Stroudsburg, Pa.
- Brodhead Cr. at Minisink Hills, Pa.
- Delaware R. at Portland, Pa.
- Paulins Kill at Blairstown, N.J.
- Paulins Kill at Columbia, N.J.
- Delaware R. at Delaware, N.J.
- Pequest R. at Huntsville, N.J.
- Pequest R. at Pequest, N.J.
- Beaver Br. nr Belvidere, N.J.
- Delaware R. at Belvidere, N.J.
- Delaware R. at Easton, Pa.
- Lehigh R. at Stoddartsville, Pa.
- Lehigh R. at Tannery, Pa.
- Dilldown Cr. nr Long Pond, Pa.
- Lehigh R. at Lehighton, Pa.
- Wild Cr. at Hatchery, Pa.
- Pohopoco Cr. nr Parryville, Pa.
- Aquashicola Cr. at Palmerton, Pa.
- Lehigh R. at Walnutport, Pa.
- L. Lehigh Cr. nr Allentown, Pa.
- L. Lehigh Cr. at Allentown, Pa.
- Jordan Cr. at Allentown, Pa.
- Monocacy Cr. at Bethlehem, Pa.
- Lehigh R. at Bethlehem, Pa.
- Saucon Cr. at Lanark, Pa.
- S. Br. Saucon Cr. at Friedensville, Pa.
- Saucon Cr. at Friedensville, Pa.
- Lake Hopatcong at Landing, N.J.
- Musconetcong R. at outlet of Lake Hopat
- Musconetcong R. nr Hackettstown, N.J.
- Musconetcong R. nr Bloomsbury, N.J.
- Delaware R. at Riegelsville, N.J.
- Delaware R. at Milford, N.J.
- Delaware R. at Frenchtown, N.J.
- Delaware R. at Pt. Pleasant, Pa.
- Tohickon Cr. nr Pipersville, Pa.
- Tohickon Cr. at Point Pleasant, Pa.
- Delaware R. at Lumberville, Pa.
- Delaware & Raritan Canal at Kingston, N
- Delaware R. at Stockton, N.J.
- Delaware R. at Lambertville, N.J.

3



Water Years
41-1950
1951-1960
Station
1881-1890
1891-1900
1901-1910
1911-1920
1921-1930
1931-1940
1941-1950
1951-1960
Station
Delaware R. at Milford, Pa.
Delaware R. at Montague, N.J.
Delaware R. at Dingmans Ferry, Pa.
Bush Kill at Shoemakers, Pa.
Delaware R. at Flatbrookville, Pa.
Flat Brook nr Flatbrookville, N.J.
Delaware R. at Tocks Island, Pa.
Analomink Cr. at Henryville, Pa.
Brodhead Cr. at Analomink, Pa.
McMichaels Cr. at & nr Stroudsburg, Pa.
Pocono Cr. nr Stroudsburg, Pa.
McMichaels Cr. at Stroudsburg, Pa.
Brodhead Cr. at Minisink Hills, Pa.
Delaware R. at Portland, Pa.
Paulins Kill at Blairstown, N.J.
Paulins Kill at Columbia, N.J.
Delaware R. at Delaware, N.J.
Pequest R. at Huntsville, N.J.
Pequest R. at Pequest, N.J.
Beaver Br. nr Belvidere, N.J.
Delaware R. at Belvidere, N.J.
Delaware R. at Easton, Pa.
Lehigh R. at Stoddartsville, Pa.
Lehigh R. at Tannery, Pa.
Dilldown Cr. nr Long Pond, Pa.
Lehigh R. at Lehighton, Pa.
Wild Cr. at Hatchery, Pa.
Pohopoco Cr. nr Parryville, Pa.
Aquashicola Cr. at Palmerton, Pa.
Lehigh R. at Walnutport, Pa.
L. Lehigh Cr. nr Allentown, Pa.
L. Lehigh Cr. at Allentown, Pa.
Jordan Cr. at Allentown, Pa.
Monocacy Cr. at Bethlehem, Pa.
Lehigh R. at Bethlehem, Pa.
Saucon Cr. at Lanark, Pa.
S. Br. Saucon Cr. at Friedensville, Pa.
Saucon Cr. at Friedensville, Pa.
Lake Hopatcong at Landing, N.J.
Musconetcong R. at outlet of Lake Hopatcong, N.J.
Musconetcong R. nr Hackettstown, N.J.
Musconetcong R. nr Bloomsbury, N.J.
Delaware R. at Riegelsville, N.J.
Delaware R. at Milford, N.J.
Delaware R. at Frenchtown, N.J.
Delaware R. at Pt. Pleasant, Pa.
Tohickon Cr. nr Pipersville, Pa.
Tohickon Cr. at Point Pleasant, Pa.
Delaware R. at Lumberville, Pa.
Delaware & Raritan Canal at Kingston, N.J.
Delaware R. at Stockton, N.J.
Delaware R. at Lambertville, N.J.
Delaware R. at Washington Crossing, N.J.
Delaware R. at Yardley, Pa.
Delaware R. at Trenton, N.J.
Assunpink Cr. at Trenton, N.J.
Crosswicks Cr. at Extonville, N.J.
Neshaminy Cr. at Rushland, Pa.
Neshaminy Cr. nr Langhorne, Pa.
N. Br. Rancocas Cr. at Pemberton, N.J.
Schuylkill R. at Pottsville, Pa.
Schuylkill R. at Schuylkill Haven, Pa.
Schuylkill R. at Landingville, Pa.
Schuylkill R. at Auburn, Pa.
L. Schuylkill R. at Tamaqua, Pa.
L. Schuylkill R. at Drehersville, Pa.
L. Schuylkill R. at Molino, Pa.
Schuylkill R. at Port Clinton, Pa.
Schuylkill R. at Berne, Pa.
Tulpehocken Cr. nr Reading, Pa.
Schuylkill R. at W. Reading, Pa.
Schuylkill R. at Reading, Pa.
Schuylkill R. at Pottstown, Pa.
Perkiomen Cr. nr Frederick, Pa.
Perkiomen Cr. at Graterford, Pa.
Perkiomen Cr. at Graterford, Pa.
Schuylkill R. at Norristown, Pa.
Schuylkill R. at Conshohocken, Pa.
Wissahickon Cr. nr Philadelphia, Pa.
Schuylkill R. at Philadelphia, Pa.
Mantua Cr. at Pitman, N.J.
Darby Cr. at Lansdowne, Pa.
Crum Cr. at Woodlyn, Pa.
Ridley Cr. at Moylan, Pa.
Chester Cr. at Chester, Pa.
Oldmans Cr. nr Woodstown, N.J.
Christina R. at Coochs Bridge, Del.
White Clay Cr. above Newark, Del.
White Clay Cr. nr Newark, Del.
Mill Cr. at Stanton, Del.
Red Clay Cr. at Wooddale, Del.
W. Br. Brandywine Cr. at Coatesville, Pa.
Brandywine Cr. at Chadds Ford, Pa.
Brandywine Cr. at Wilmington, Del.
Brandywine Cr. at Wilmington, Del.
Shellpot Cr. at Wilmington, Del.
Salem R. at Woodstown, N.J.
Loper Run nr Bridgeton, N.J.
Blackbird Cr. at Blackbird, Del.
Leipsic R. nr Cheswold, Del.
Maurice R. at Norma, N.J.
Manantico Cr. nr Millville, N.J.
Murderkill R. nr Felton, Del.
Primehook Cr. nr Milton, Del.
Indian R. at Stockley, Del.

4



LEGEND

- Recorder station
- Non-recording station (staff, wire wt. chain.)
- Discharge record by other than U.S.G.S. / Non-recording station (staff, wire wt. chain.)
- Gage heights or stage only.

REVIEW REPORT

DELAWARE RIVER BASIN

PERIODS OF RECORD OF STREAM GAGING STATIONS

In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

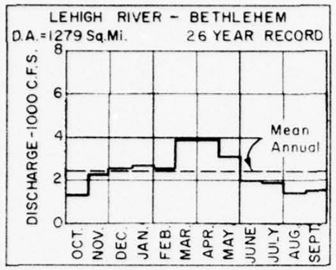
Scale as Shown
Philadelphia District
January 59

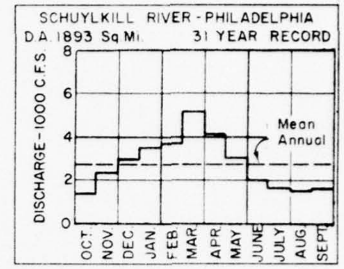
Drawer No. 228

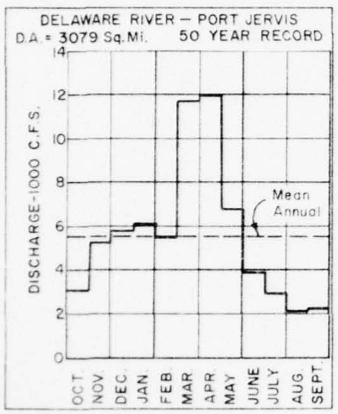
File No. 28094

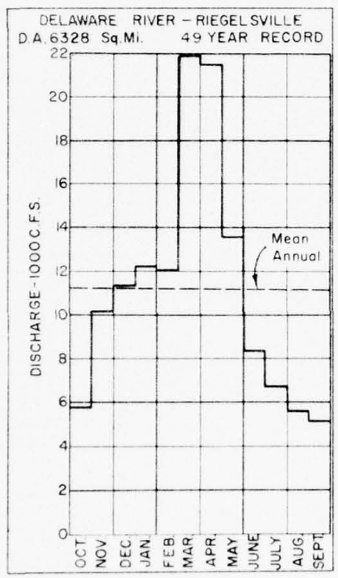
PLATE NO. 19

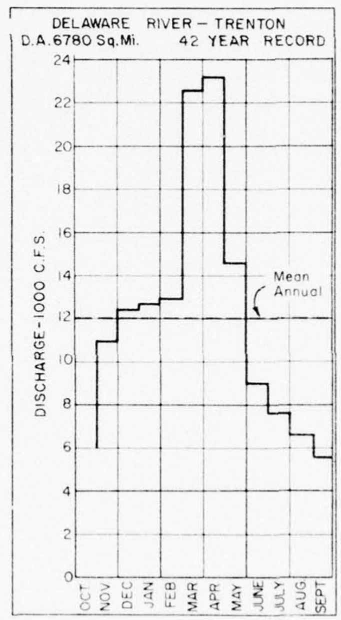
CORPS OF ENGINEERS U.S. ARMY

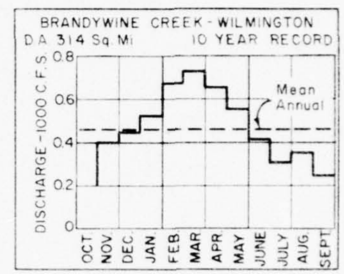












REVIEW REPORT

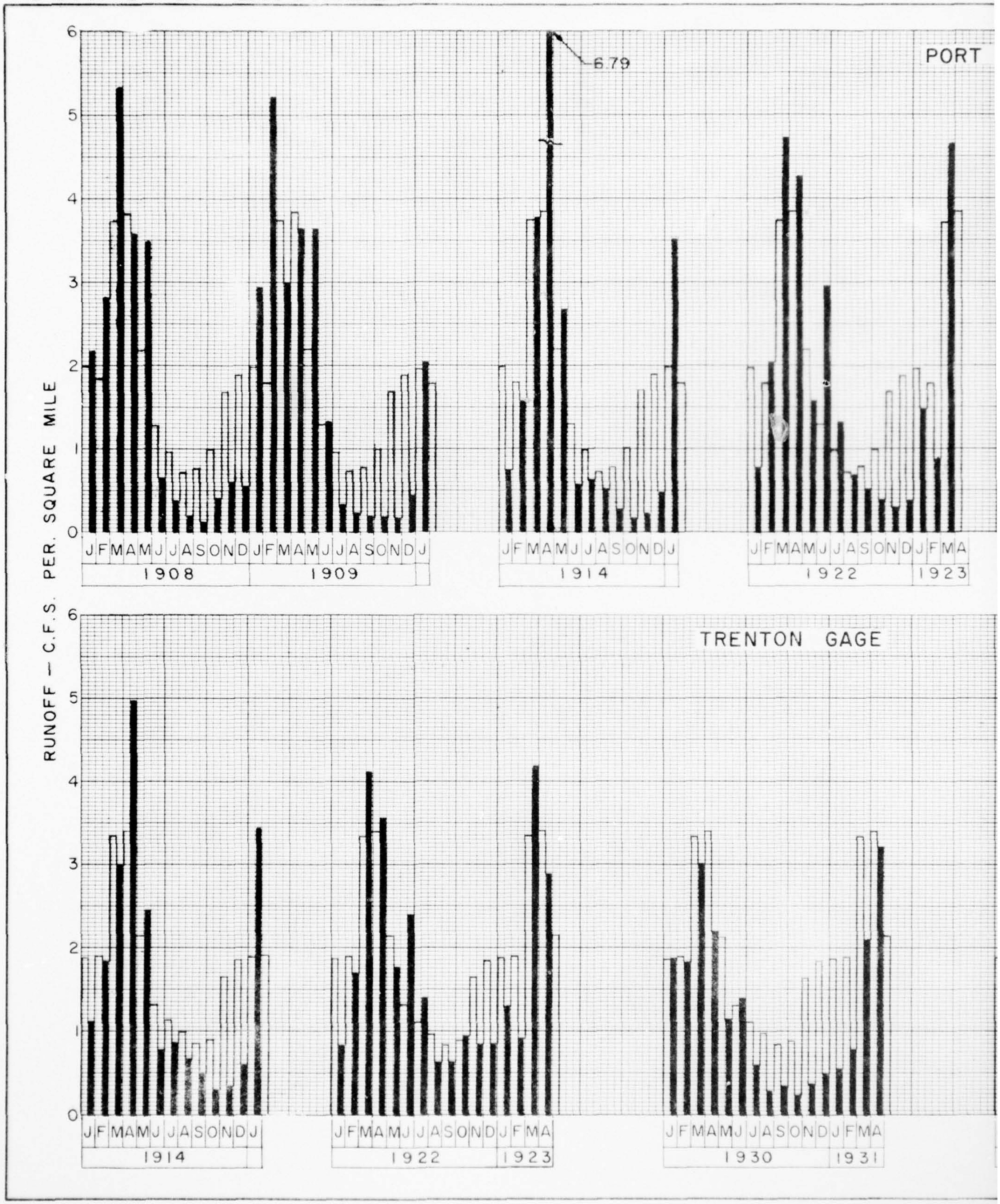
DELAWARE RIVER BASIN

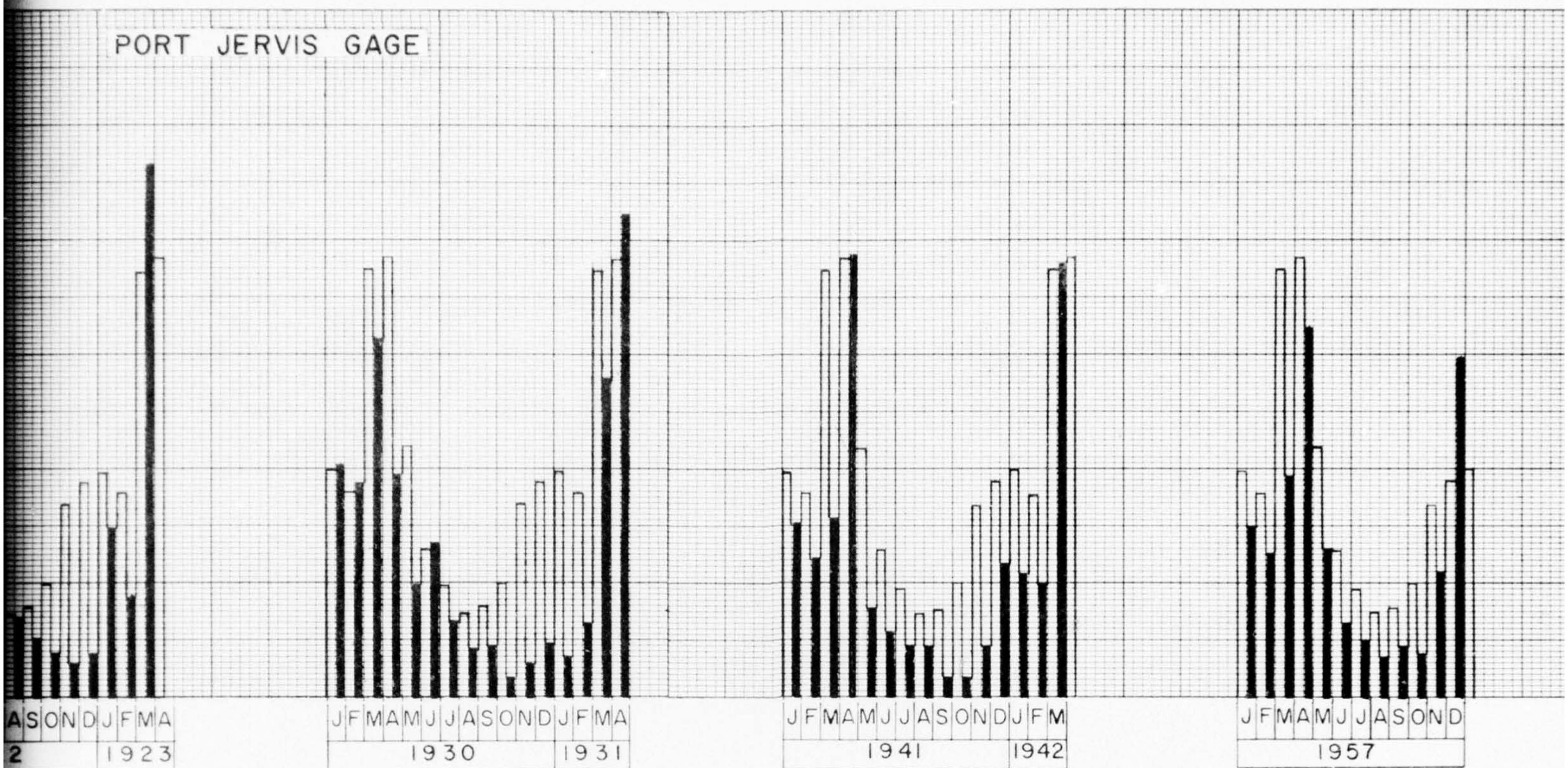
NORMAL MEAN MONTHLY FLOWS
AT SELECTED
STREAM GAGING STATIONS

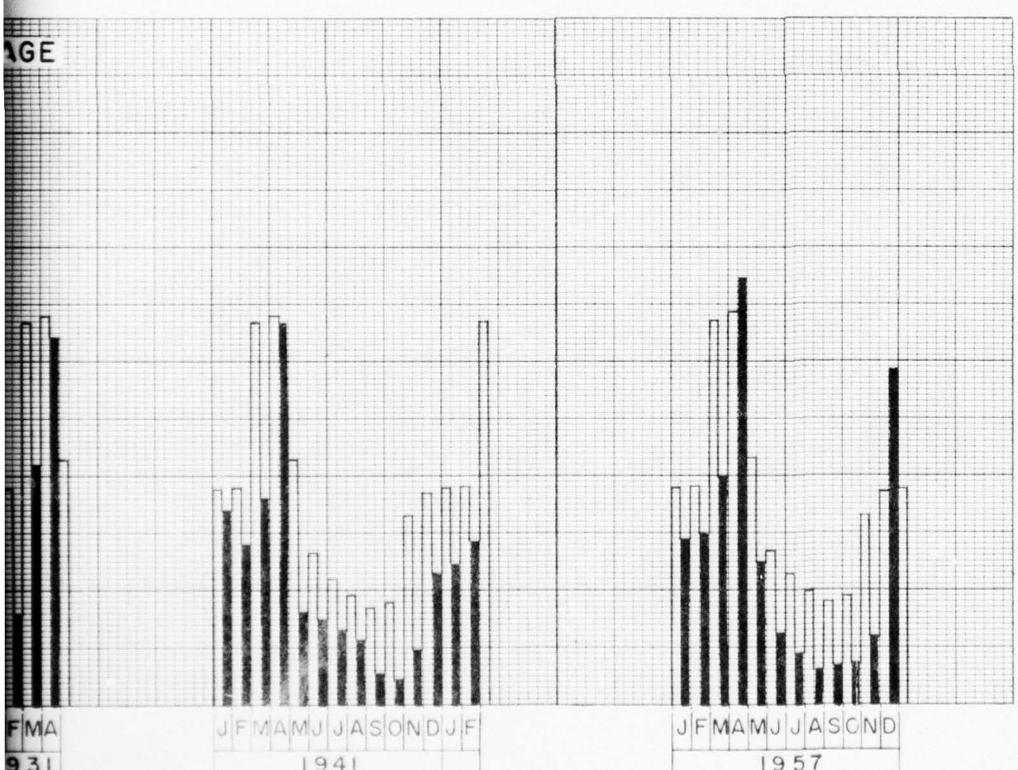
In 1 Sheet — Scales as Shown
Corps of Engineers — Philadelphia District
Philadelphia, Pa. — November 1958

Drawer No 228 — File No. 28095

CORPS OF ENGINEERS







ACTUAL MONTHLY RUNOF

MEAN MONTHLY RUNOFF

REVIEW REPORT

DELAWARE RIVER BASI

COMPARISON OF ACTUAL MONTHL RUNOFF WITH MEAN MONTHLY RUNOFF DURING DEFICIENT PERIOD

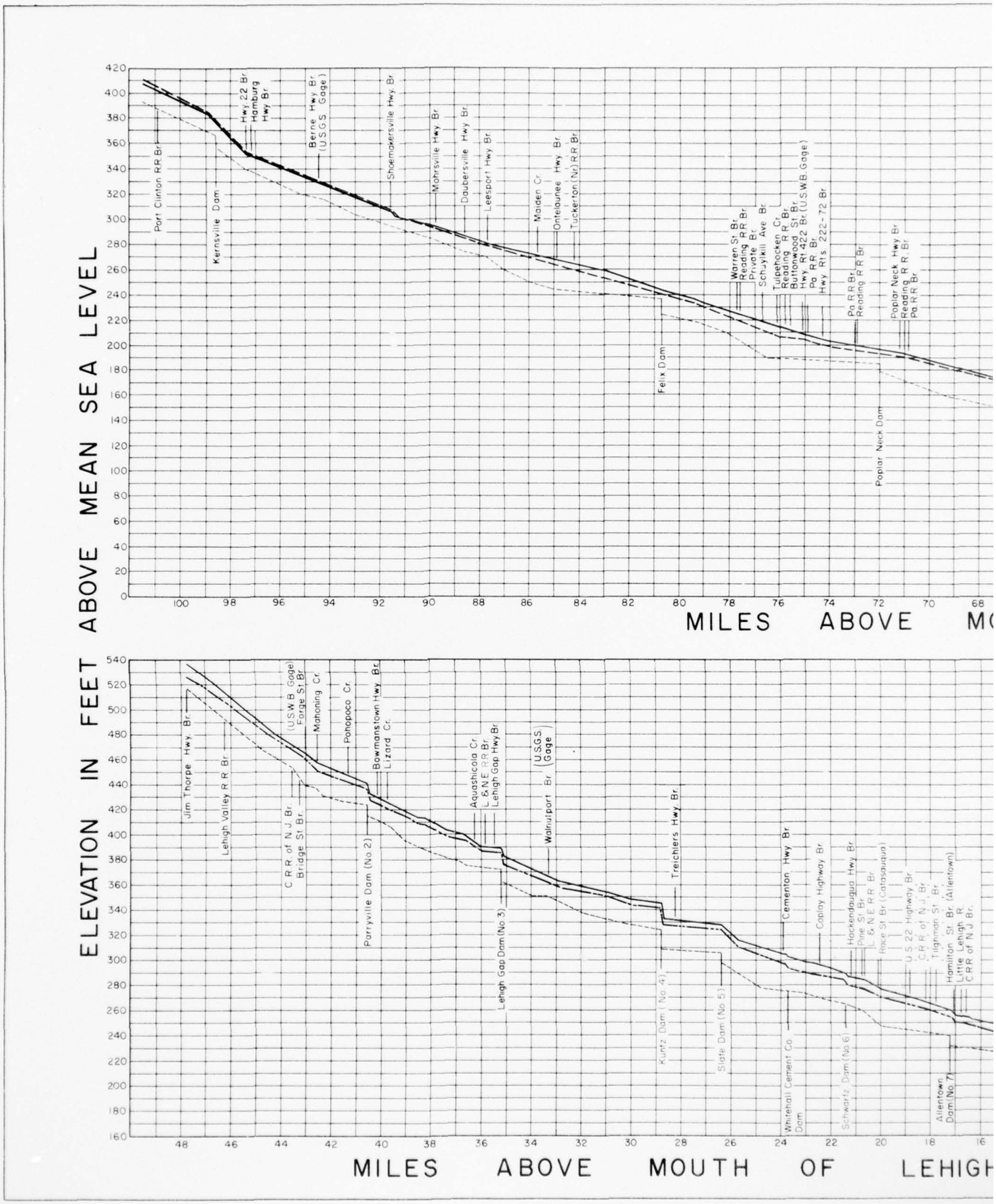
In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

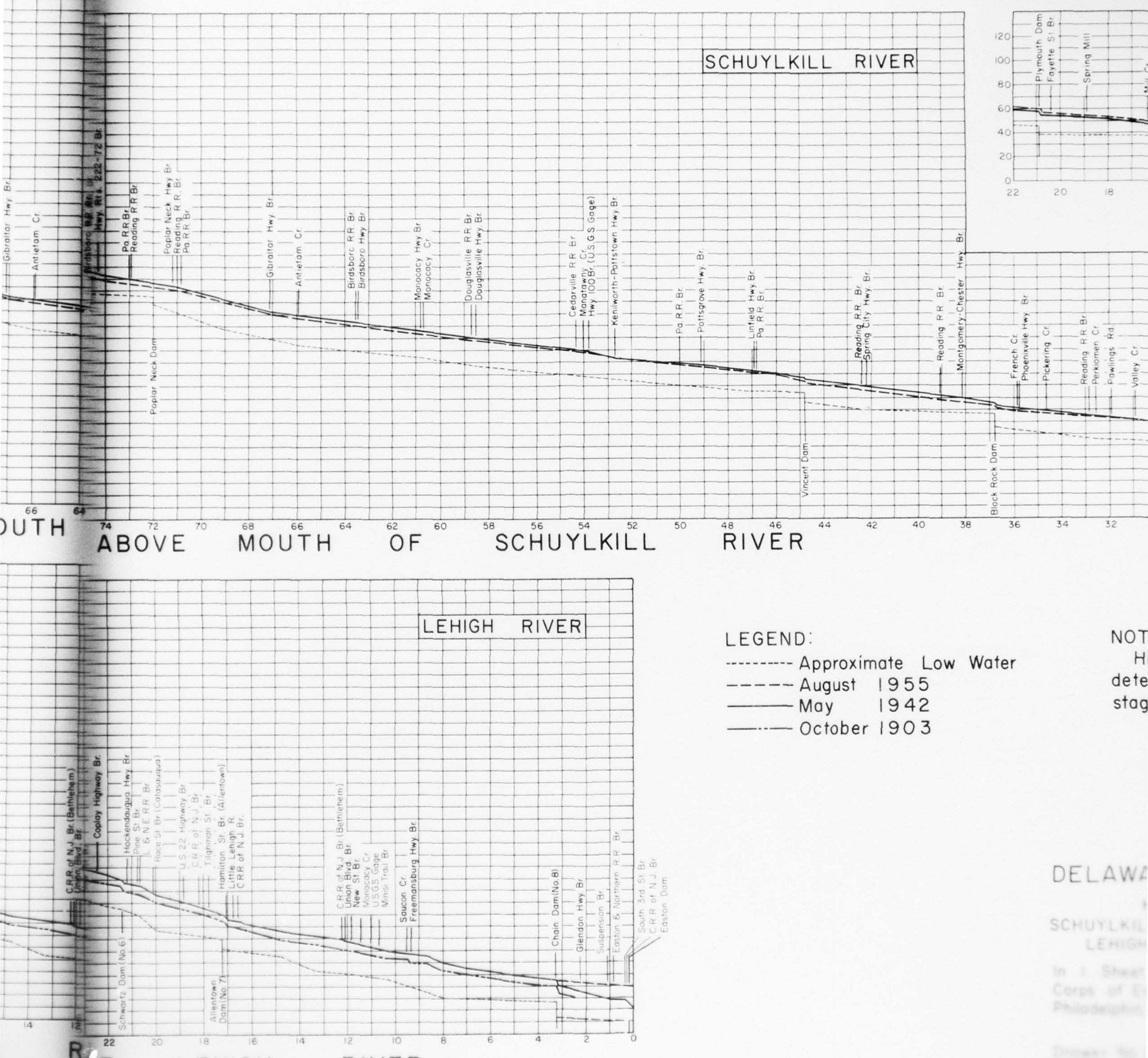
Scales as Sh
Philadelphia Dist
January

Drawer No. 228

File No. 28096

CORPS OF ENGINEERS




SCHUYLKILL RIVER
ABOVE MOUTH OF SCHUYLKILL RIVER
LEHIGH RIVER
OF LEHIGH RIVER
LEGEND:
Approximate Low Water
August 1955
May 1942
October 1903
Gibraltar Hwy. Br.
Antietam Cr.
Birdsboro R.R. Br.
Hwy. Rts. 222-72 Br.
Pa. R.R. Br.
Reading R.R. Br.
Poplar Neck Hwy. Br.
Poplar Neck Dam
Birdsboro Hwy. Br.
Monocacy Hwy. Br.
Monocacy Cr.
Douglasville R.R. Br.
Douglasville Hwy. Br.
Cedarville R.R. Br.
Manatawny Cr.
Hwy. 100 Br. (U.S.G.S. Gage)
Kenilworth-Pottstown Hwy. Br.
Pottsgrove Hwy. Br.
Linfield Hwy. Br.
Vincent Dam
Spring City Hwy. Br.
Montgomery-Chester Hwy. Br.
Black Rock Dam
French Cr.
Phoenixville Hwy. Br.
Pickering Cr.
Perkiomen Cr.
Pawlings Rd.
Valley Cr.
Plymouth Dam
Fayette St. Br.
Spring Mill
Coplay Highway Br.
Hockendauqua Hwy. Br.
Pine St. Br.
L. & N.E. R.R. Br.
Race St. Br. (Catasauqua)
U.S. 22 Highway Br.
C.R.R. of N.J. Br.
Tilghman St. Br.
Hamilton St. Br. (Allentown)
Little Lehigh R.
Schwartz Dam (No. 6)
Allentown Dam (No. 7)
C.R.R. of N.J. Br. (Bethlehem)
Union Blvd. Br.
New St. Br.
Monocacy Cr.
U.S.G.S. Gage
Minsi Trail Br.
Saucon Cr.
Freemansburg Hwy. Br.
Chain Dam (No. 8)
Glendon Hwy. Br.
Suspension Br.
Easton & Northern R.R. Br.
South 3rd St. Br.
Easton Dam
NOT
DELAWA
SCHUYLKIL
LEHIGH

AD-A043 796 ARMY ENGINEER DISTRICT PHILADELPHIA PA F/G 8/6

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF TH--ETC(U)

DEC 60

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3 OF 3

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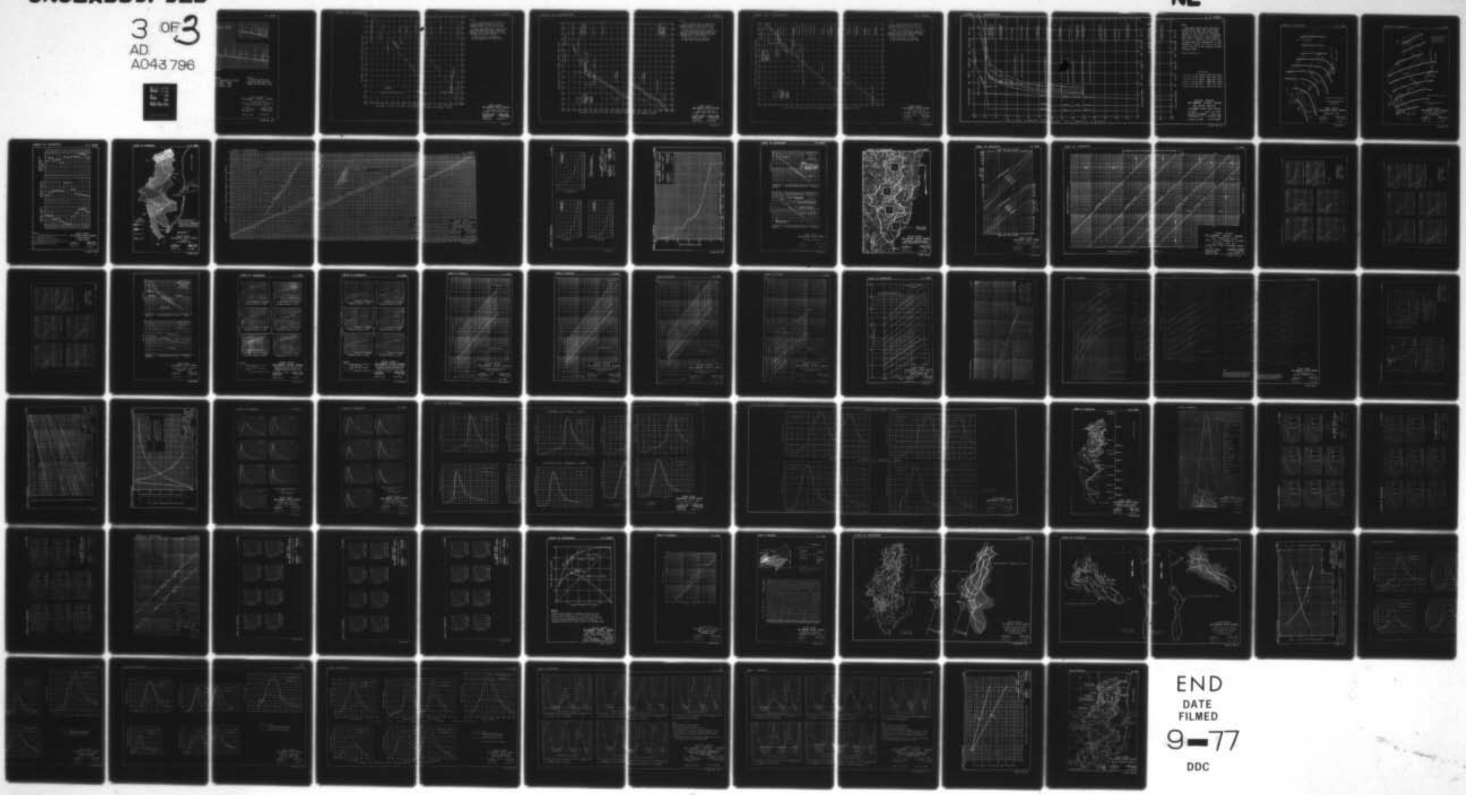

END

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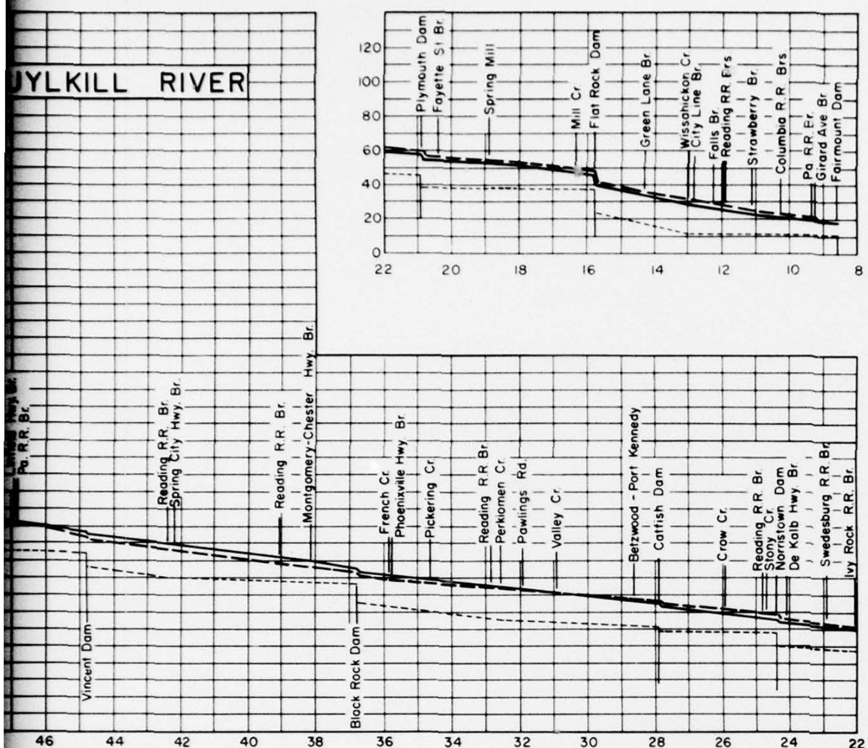
U.S. ARMY 3



VER

EGEND:

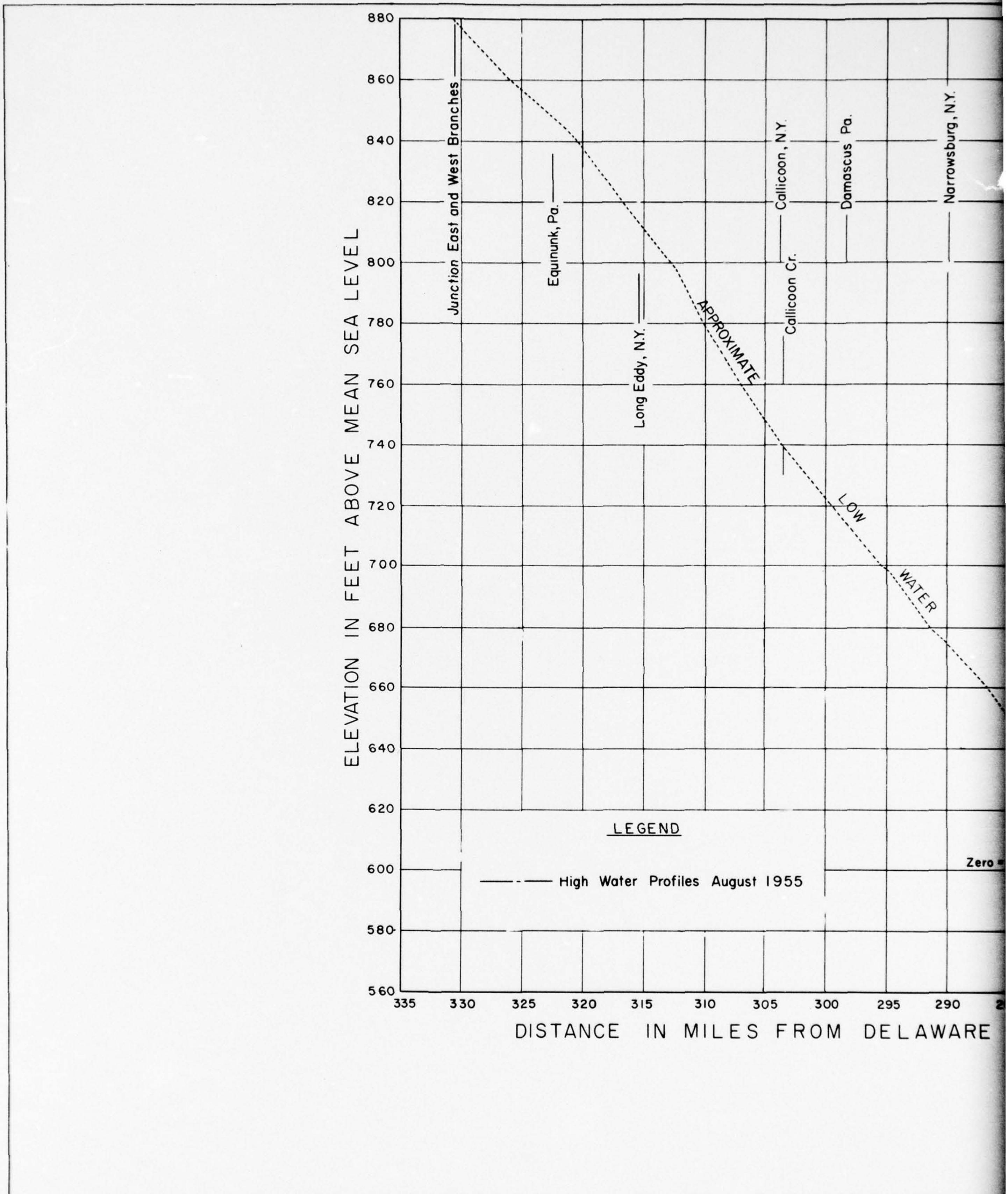
------- Approximate Low Water
---- August 1955
—— May 1942
-·-·— October 1903

NOTES:

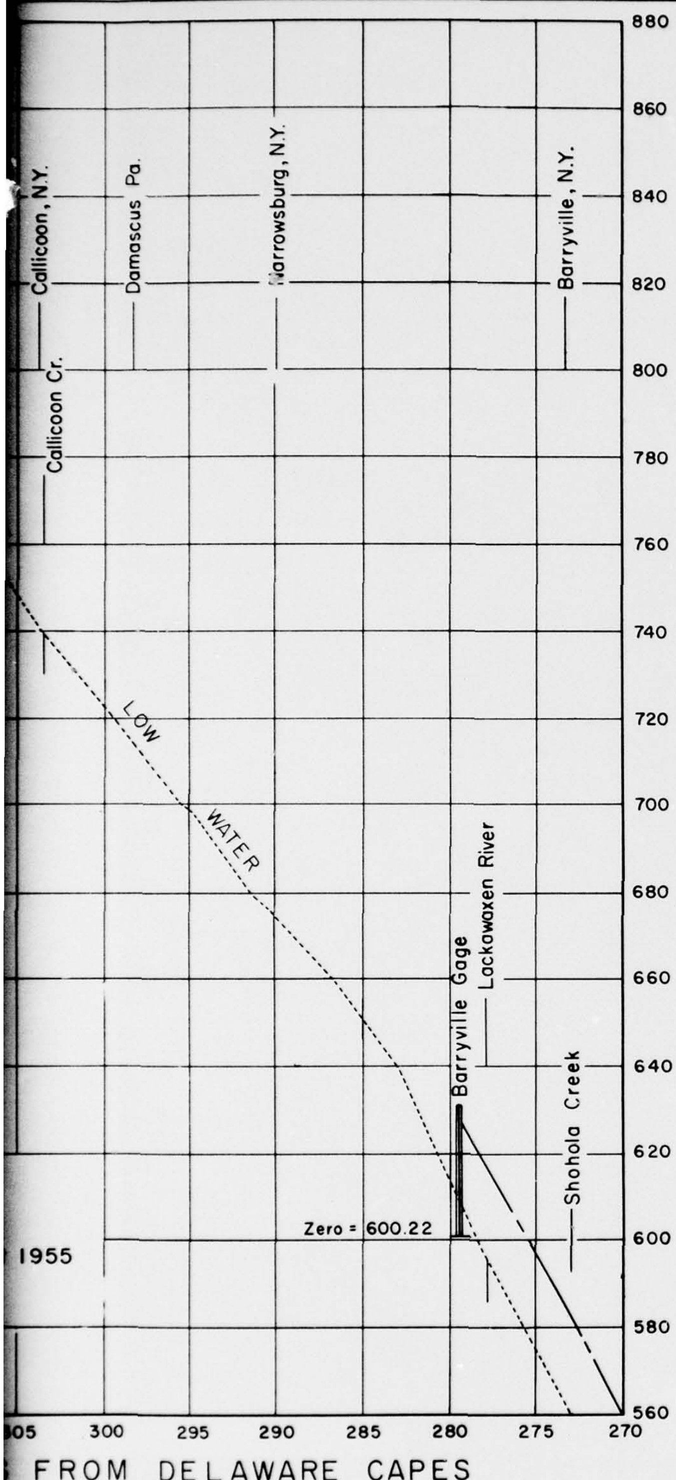
High water profiles were determined from peak flood stages and high water marks.

REVIEW REPORT
DELAWARE RIVER BASIN
HIGH WATER PROFILES
SCHUYLKILL RIVER-MILE 101 to MILE 8
LEHIGH RIVER-MILE 48 to MILE 0

In 1 Sheet	Scales as Shown
Corps of Engineers	Philadelphia District
Philadelphia, Pa.	7 December 1959
Drawer No. 228	File No. 28097


ELEVATION IN FEET ABOVE MEAN SEA LEVEL
880
860
840
820
800
780
760
740
720
700
680
660
640
620
600
580
560
Junction East and West Branches
Equinunk, Pa.
Long Eddy, N.Y.
Callicoon, N.Y.
Callicoon Cr.
Damascus Pa.
Narrowsburg, N.Y.
APPROXIMATE LOW WATER
LEGEND
High Water Profiles August 1955
Zero =
335
330
325
320
315
310
305
300
295
290
DISTANCE IN MILES FROM DELAWARE

U.S. ARMY



NOTES:

1. Zero of mileage is point of intersection of centerline of channel in Delaware Bay with a line connecting Cape May Light and the tip of Cape Henlopen, as shown on Coast Chart No. 1219.

2. Mileage from Delaware Capes to Bridge Street, Trenton, N.J. computed from channel distances as determined by field surveys. Mileage above Bridge Street, determined by scaling distances on U.S.G.S. quadrangles whose scale is 1:62,500.

3. High water profiles were determined from gage readings and high water marks.

REVIEW REPORT

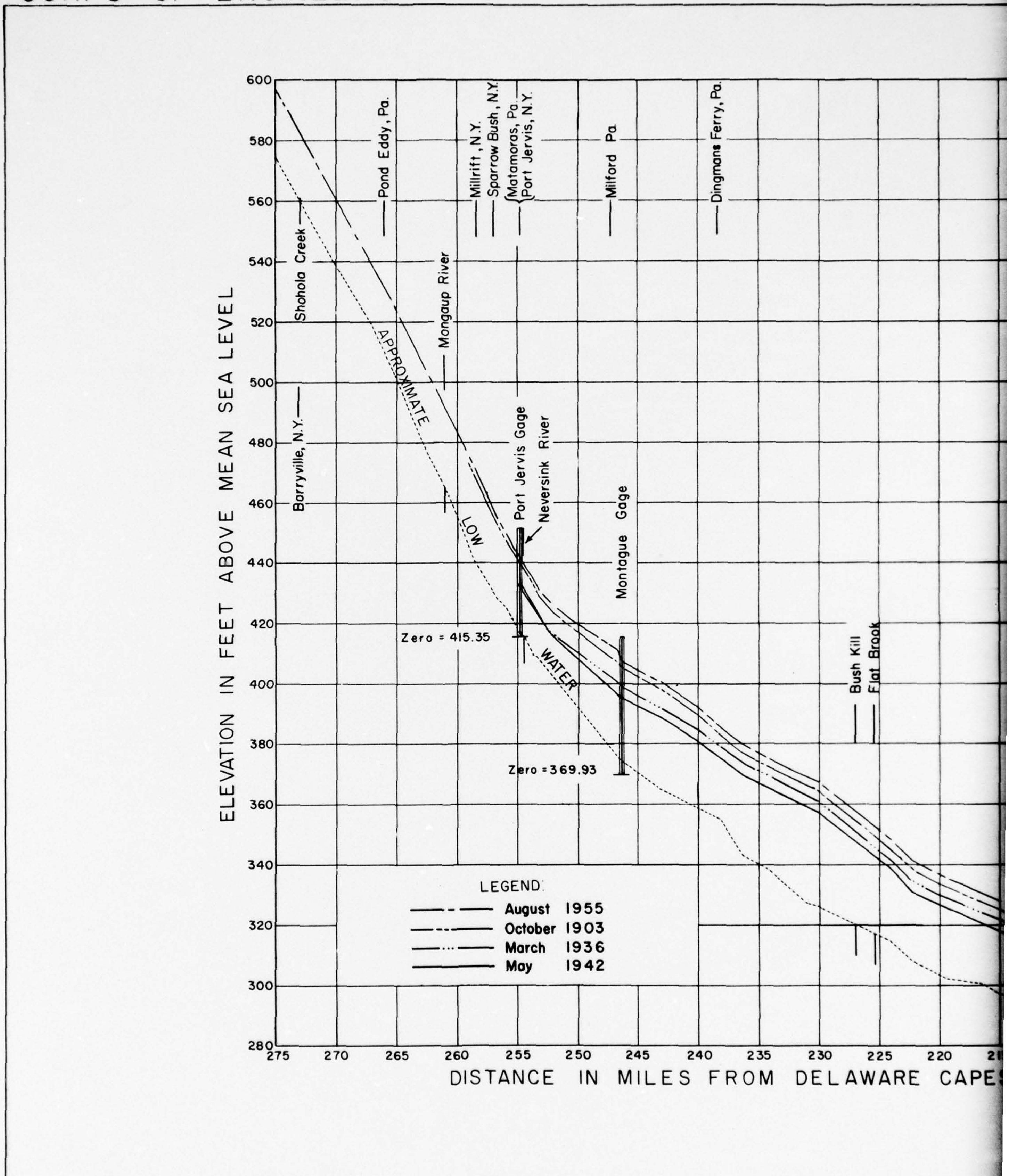
DELAWARE RIVER BASIN

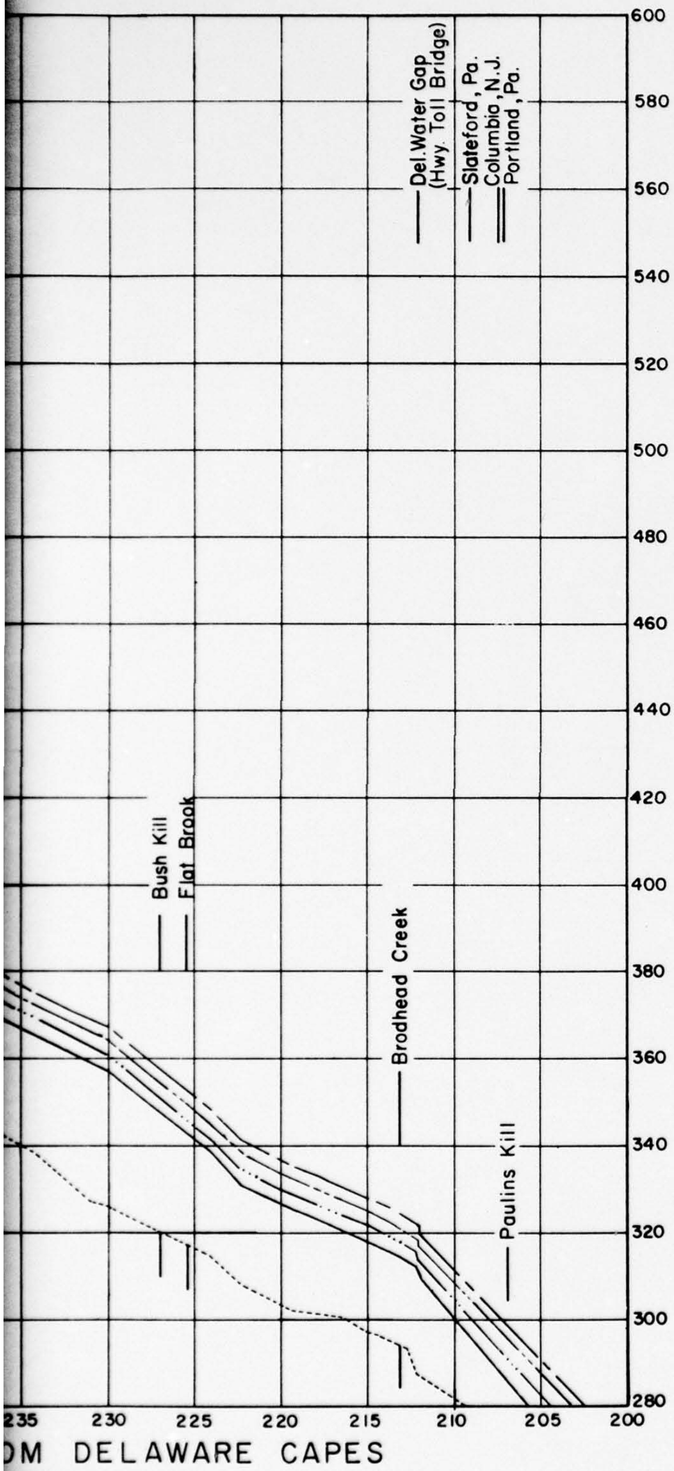
HIGH WATER PROFILES

DELAWARE RIVER MILE 330.7 to 275

In 3 Sheets Sheet 1	**Scales as Shown**
Corps of Engineers	**Philadelphia District**
Philadelphia, Pa.	**30 Dec. 1959**
Drawer No. 228	**File No.** 28098

CORPS OF ENGINEERS





NOTES:

1. Zero of mileage is point of intersection of centerline of channel in Delaware Bay with a line connecting Cape May Light and the tip of Cape Henlopen, as shown on Coast Chart No. 1219.

2. Mileage from Delaware Capes to Bridge Street, Trenton, N.J. computed from channel distances as determined by field surveys. Mileage above Bridge Street, determined by scaling distances on U.S.G.S. quadrangles whose scale is 1:62,500.

3. High water profiles were determinded from gage readings and high water marks.

REVIEW REPORT

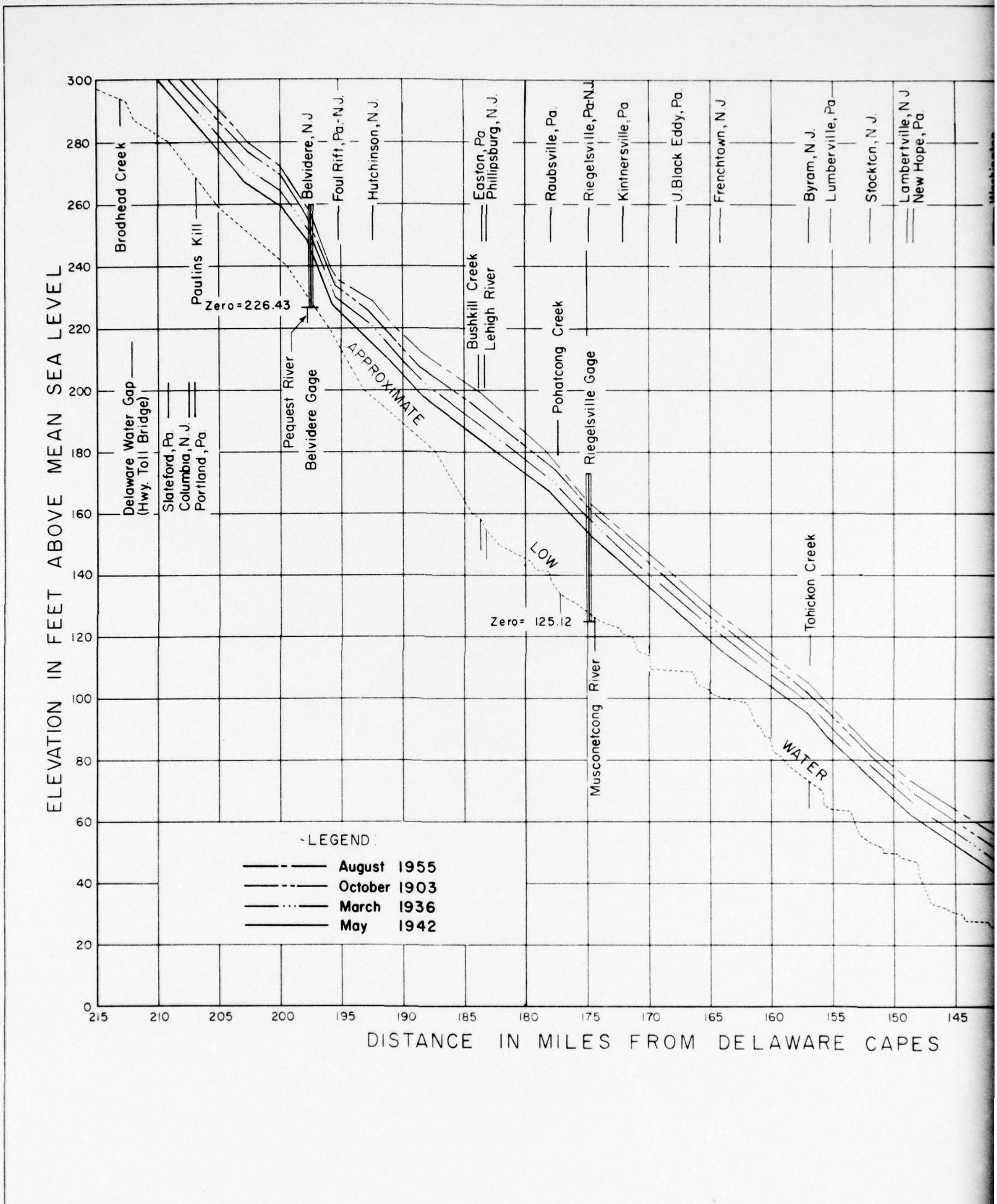
DELAWARE RIVER BASIN

HIGH WATER PROFILES
DELAWARE RIVER MILE 275 to 210

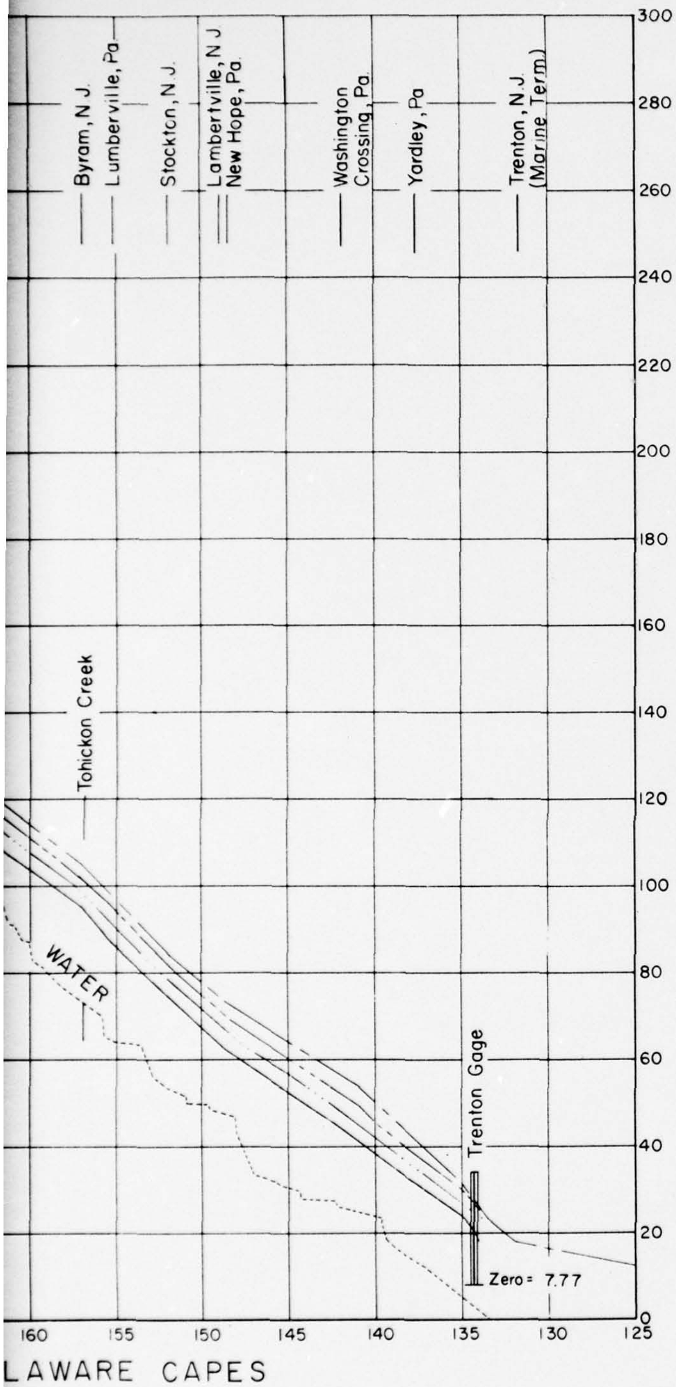
In 3 Sheets Sheet 2 Scales as shown
Corps of Engineers Philadelphia District
Philadelphia, Pa. 30 Dec. 1959

Drawer No. 228 File No. 28099

CORPS OF ENGINEERS



U. S. ARMY



NOTES

1. Zero of mileage is point of intersection of centerline of channel in Delaware Bay with a line connecting Cape May Light and the tip of Cape Henlopen, as shown on Coast Chart No. 1219.

2. Mileage from Delaware Capes to Bridge Street, Trenton, N.J. computed from channel distances as determined by field surveys. Mileage above Bridge Street, determined by scaling distances on U.S.G.S. quadrangles whose scale is 1:62,500.

3. High water profiles were determined from gage readings and high water marks.

REVIEW REPORT

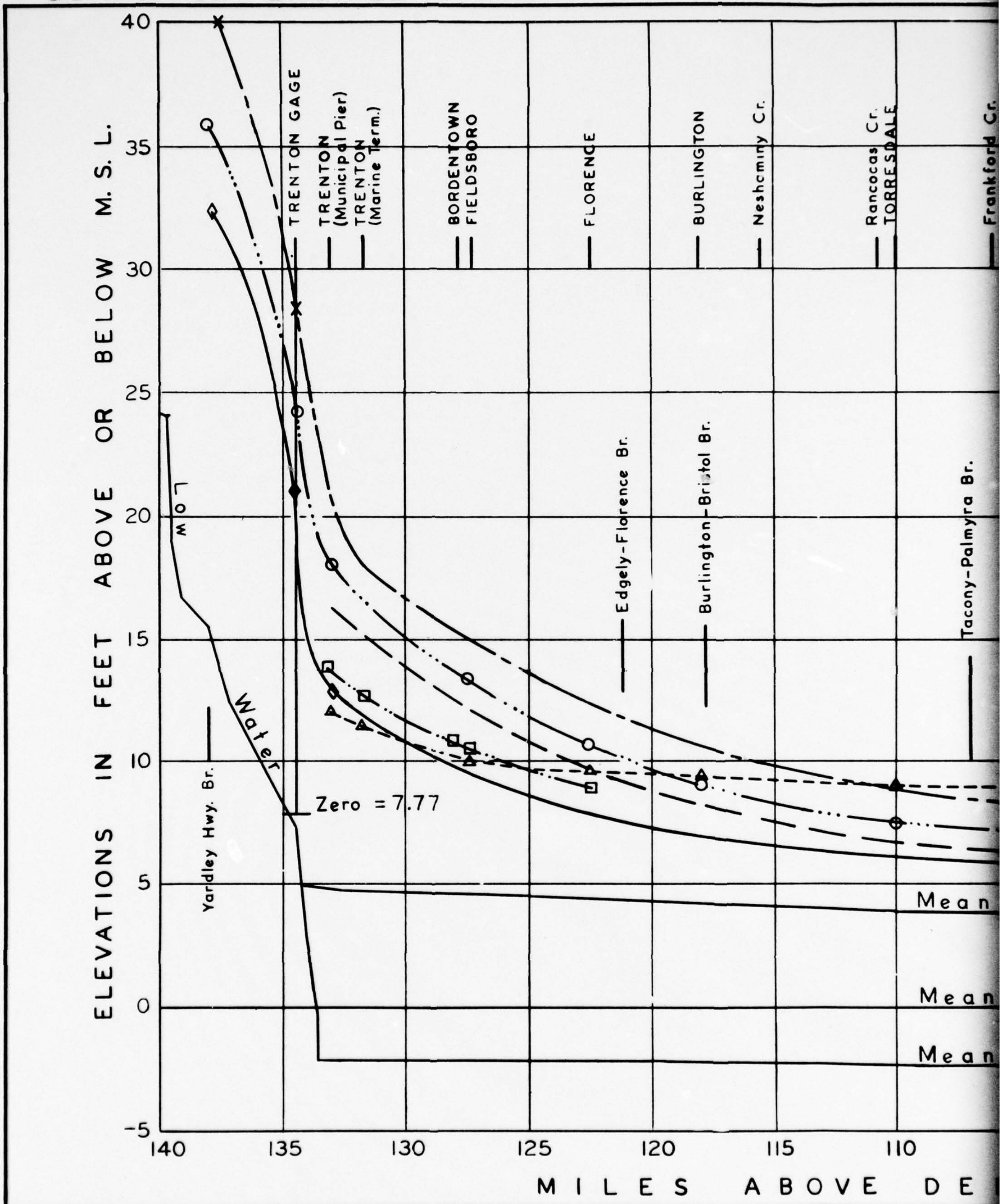
DELAWARE RIVER BASIN

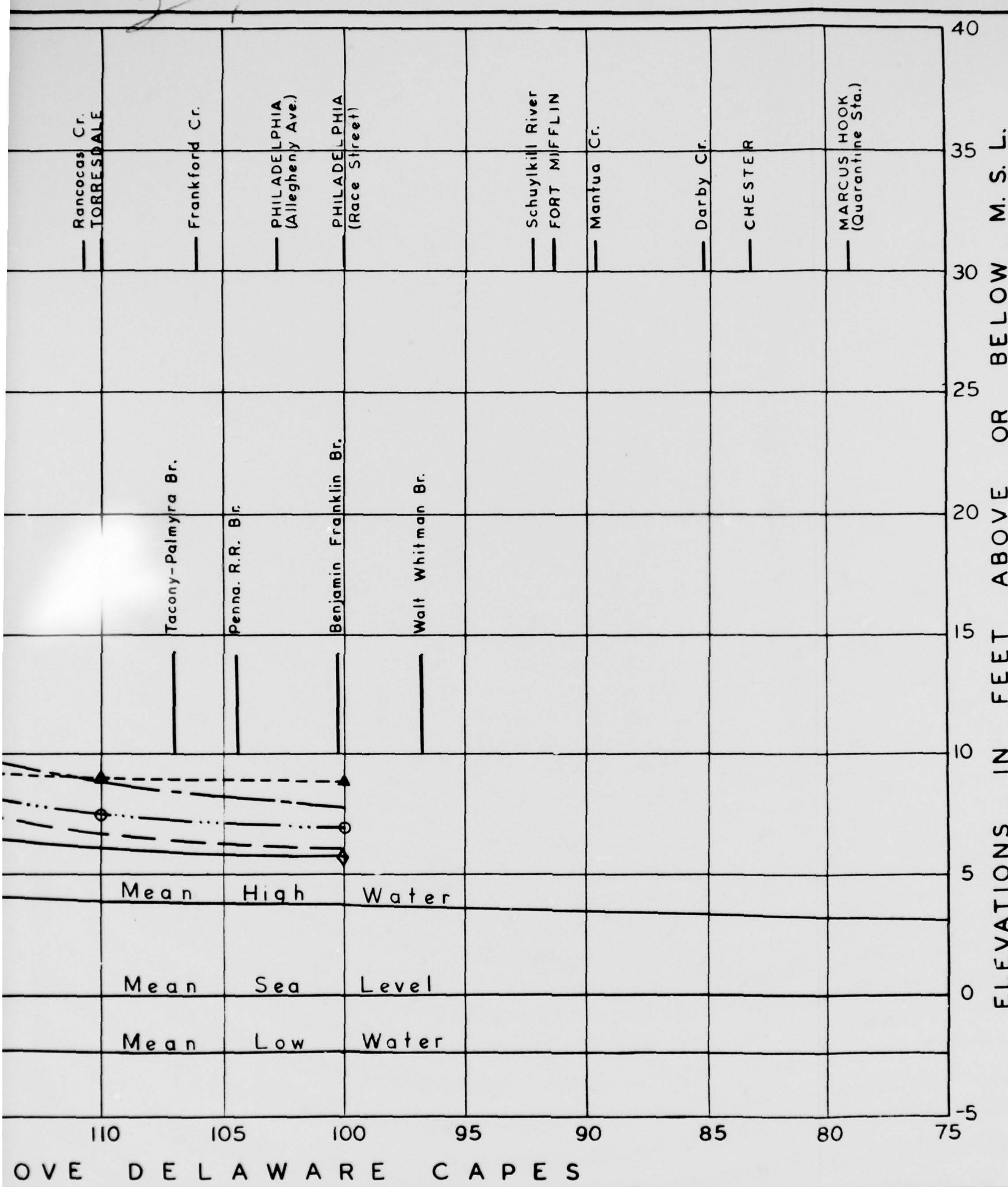
HIGH WATER PROFILES

DELAWARE RIVER MILE 210 to 134.5

In 3 Sheets	Sheet 3	Scales as Shown
Corps of Engineers		Philadelphia District
Philadelphia, Pa.		23 Oct. 1959
Drawer No. 228		File No. 28100

CORPS OF ENGINEERS





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U. S. ARMY

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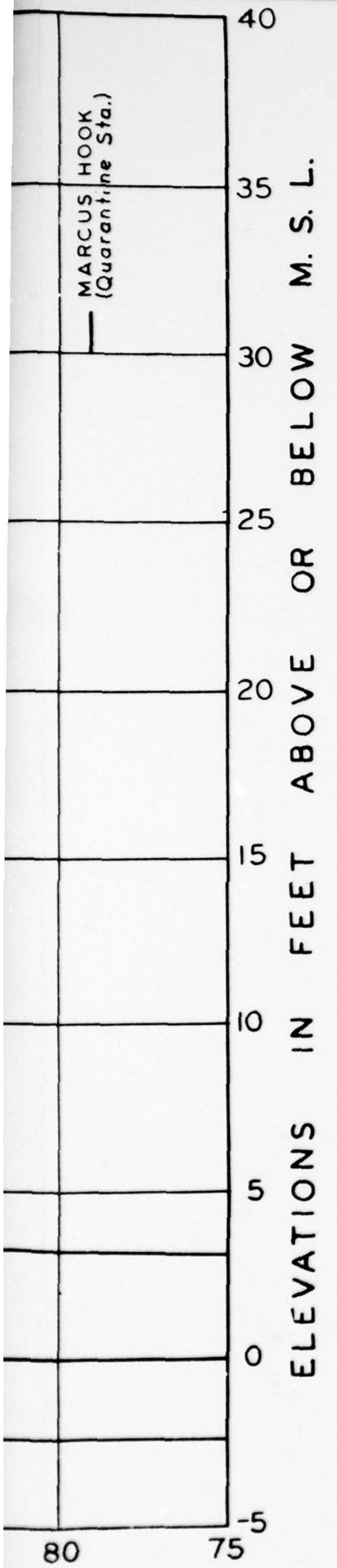


NOTE:

High water profiles shown have been estimated from data taken from various sources but are indicative of high water conditions in the section of the Delaware River below Trenton, N.J. Many variations may occur in profiles in this section due to wide ranges and combinations of flows generated in either the fluvial or the tidal section. Symbols on flow profiles indicated recorded stages.

LEGEND

- 24 August 1933 High Water
- 25 August 1933 High Water
- 13 March 1936 High Water
- 19 March 1936 High Water
- 24 May 1942 High Water
- 20 August 1955 High Water

REVIEW REPORT

DELAWARE RIVER BASIN

HIGH WATER PROFILES

DELAWARE RIVER MILE 138 to 100

In 1 Sheet Scales as Shown

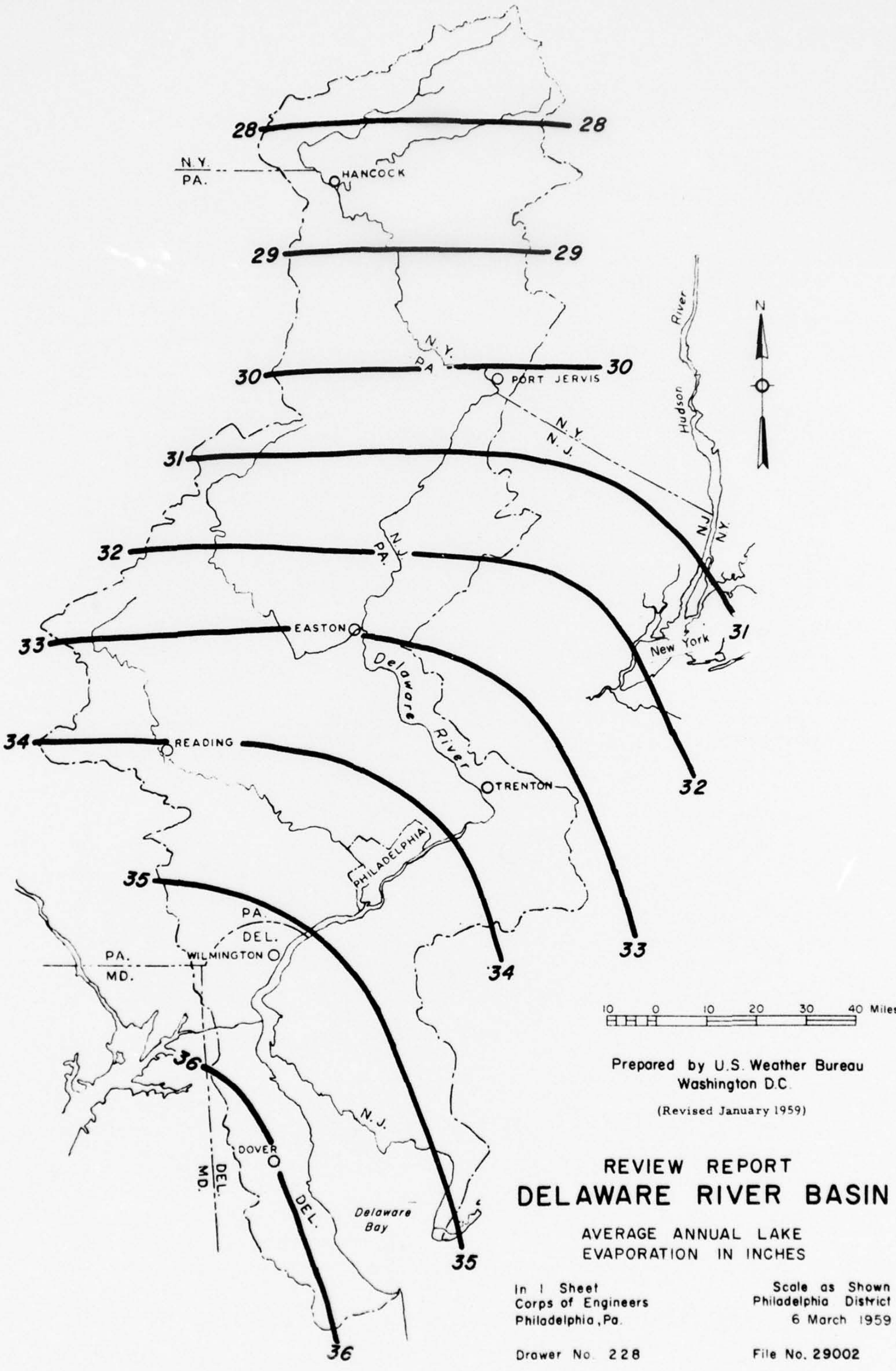
Corps of Engineers Phila. Dist.

Philadelphia, Pa. November 1958

Drawer No. 228 File No. 29001

PLATE NO. 26

CORPS OF ENGINEERS U.S. ARMY



Prepared by U.S. Weather Bureau
Washington D.C.

(Revised January 1959)

REVIEW REPORT
DELAWARE RIVER BASIN

AVERAGE ANNUAL LAKE
EVAPORATION IN INCHES

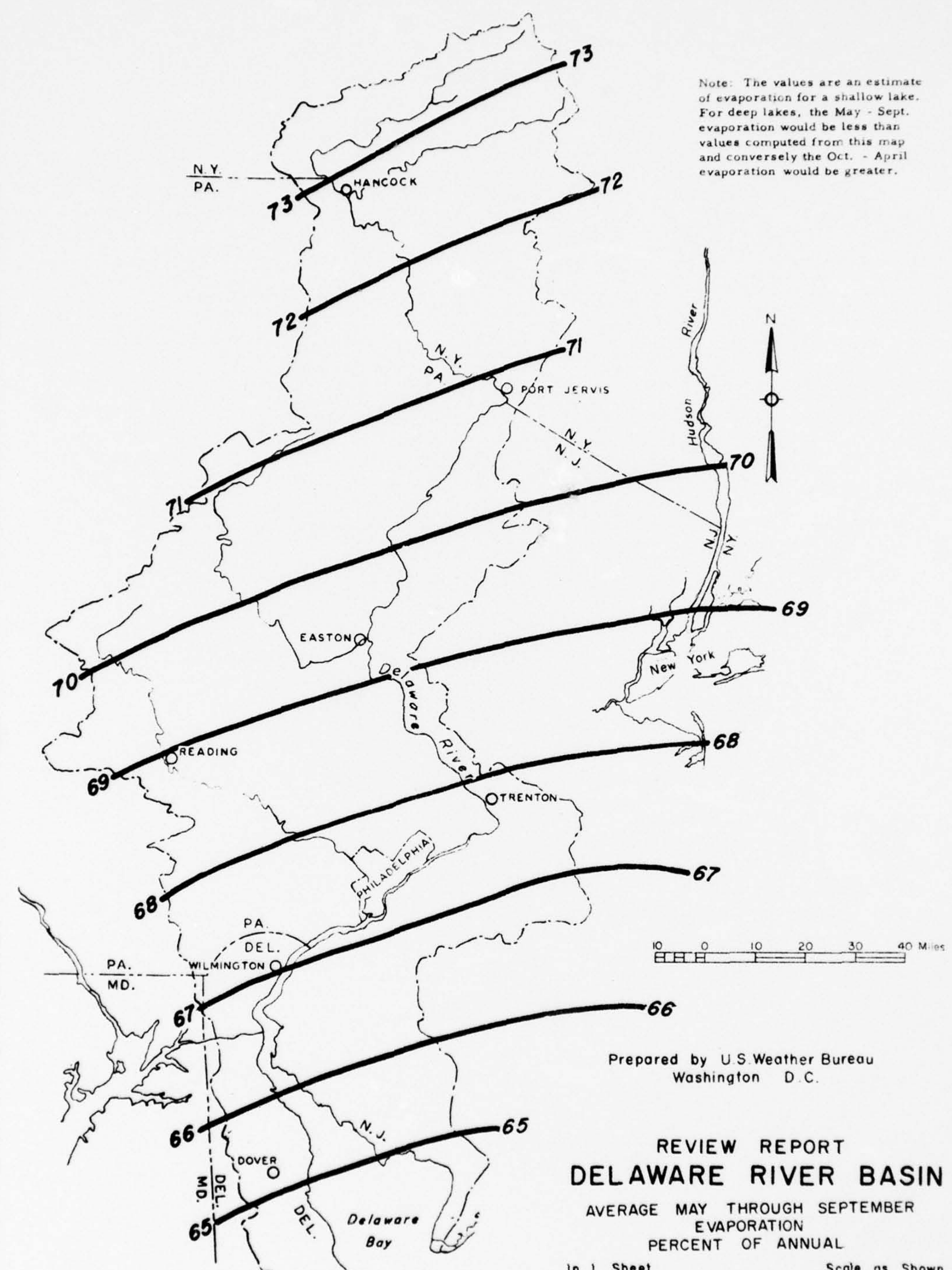
In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scale as Shown
Philadelphia District
6 March 1959

Drawer No. 228

File No. 29002

PLATE NO. 27



REVIEW REPORT

DELAWARE RIVER BASIN

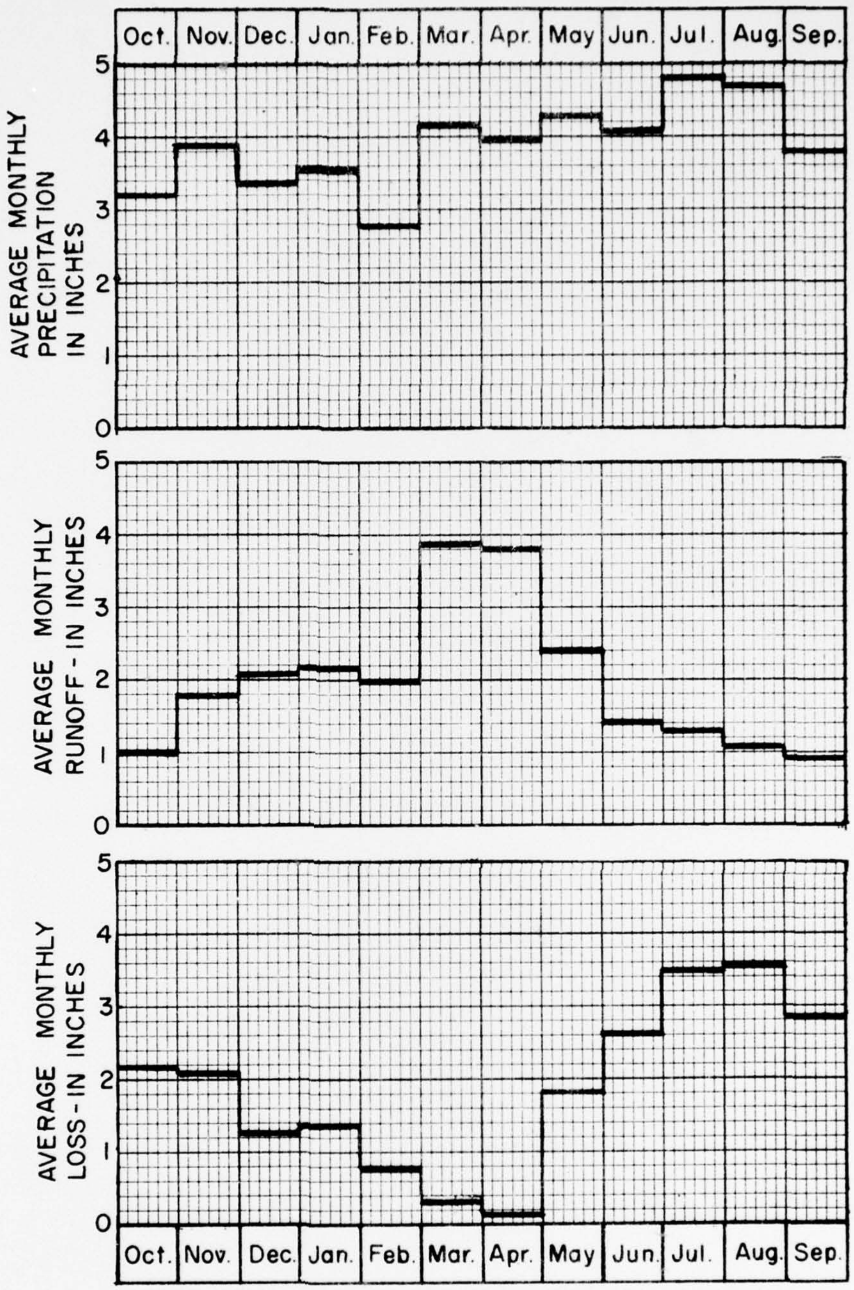
AVERAGE MAY THROUGH SEPTEMBER
EVAPORATION
PERCENT OF ANNUAL

In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scale as Shown
Philadelphia District
6 March 1959

Drawer No. 228

File No. 29003



Notes:

1. Plotted data are basin averages for area above Trenton.
2. Monthly losses include evapotranspiration and transient loss to ground water recharge.

REVIEW REPORT

DELAWARE RIVER BASIN

AVERAGE MONTHLY

WATER BALANCE

In 1 Sheet | Scale as Shown
Corps of Engineers | Philadelphia District
Philadelphia, Pa. | DECEMBER 1958

Drawer No 228 | File No. 29004

CORPS OF ENGINEERS U. S. ARMY

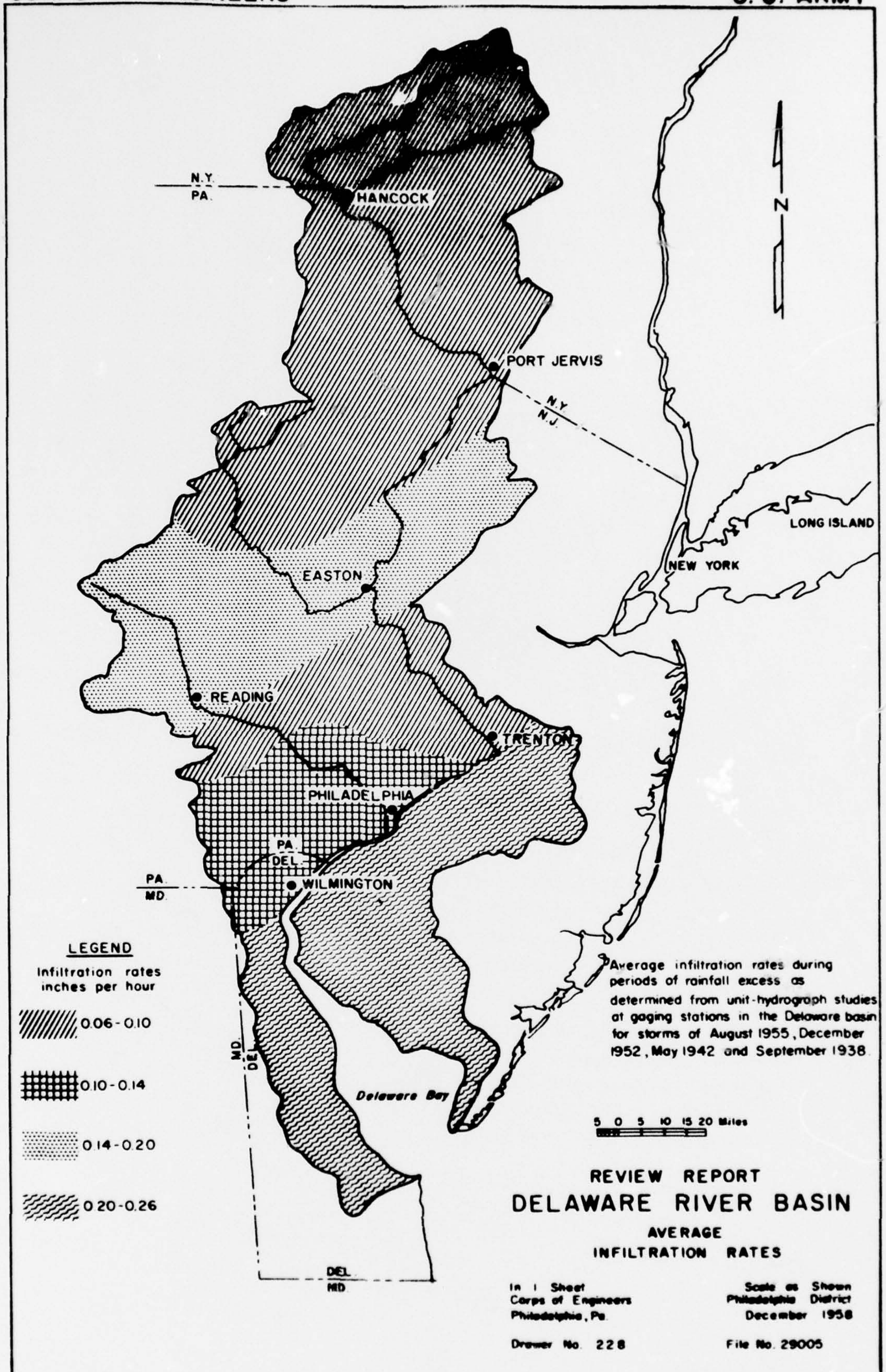
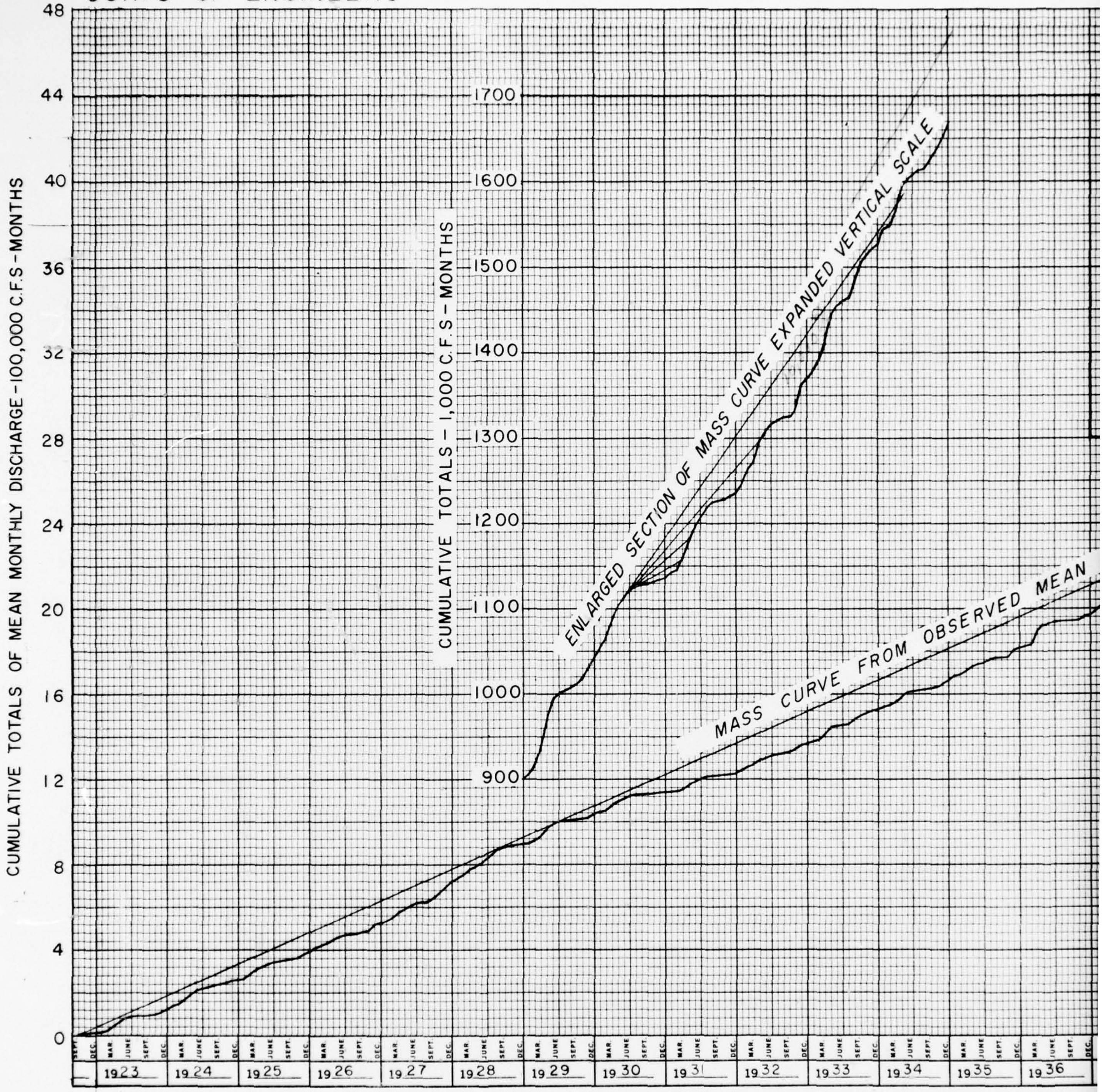


PLATE NO. 30

CORPS OF ENGINEERS



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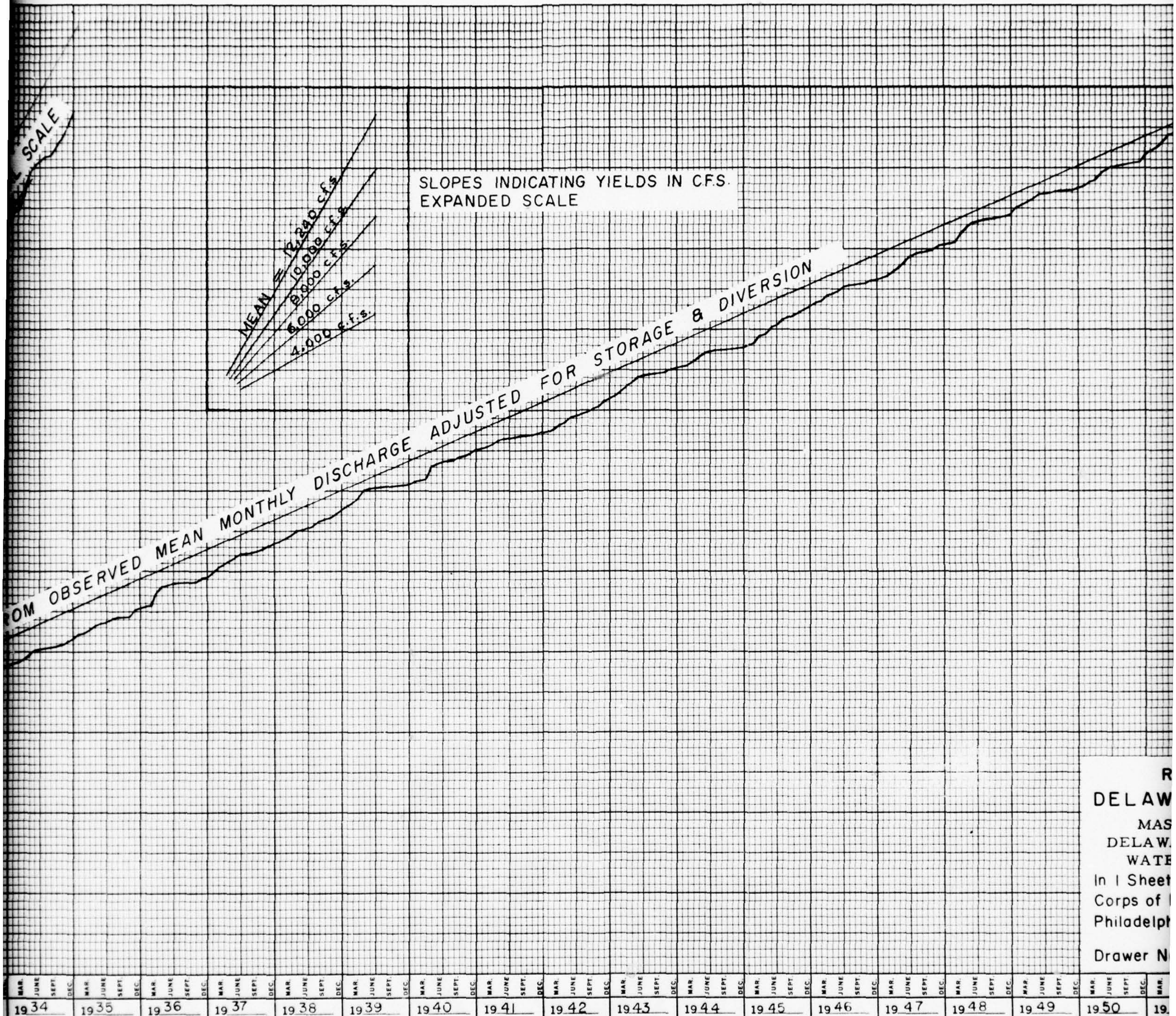
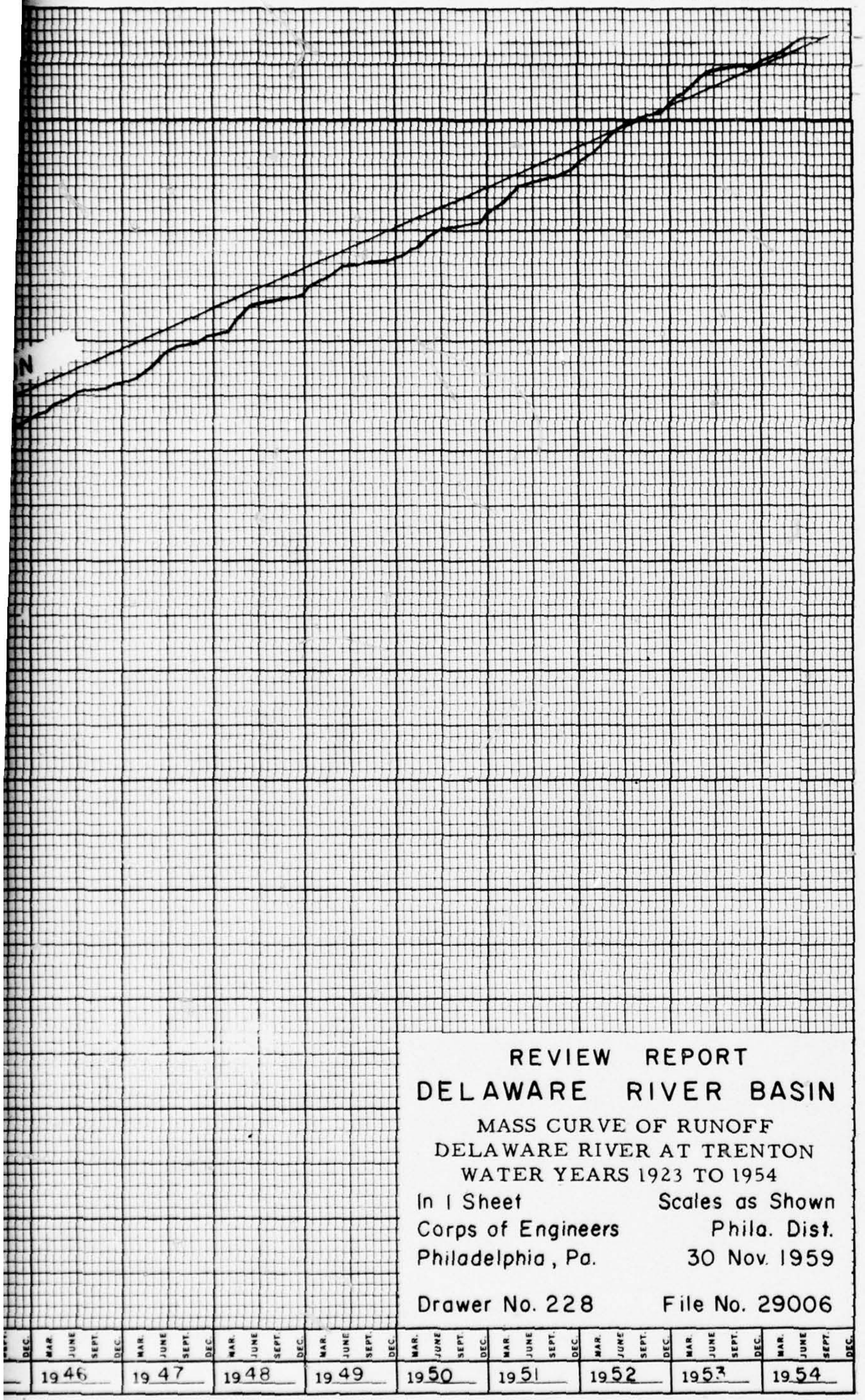


R
DELAW
MAS
DELAW
WATE
In 1 Sheet
Corps of
Philadelph
Drawer N

3

U. S. ARMY



REVIEW REPORT

DELAWARE RIVER BASIN

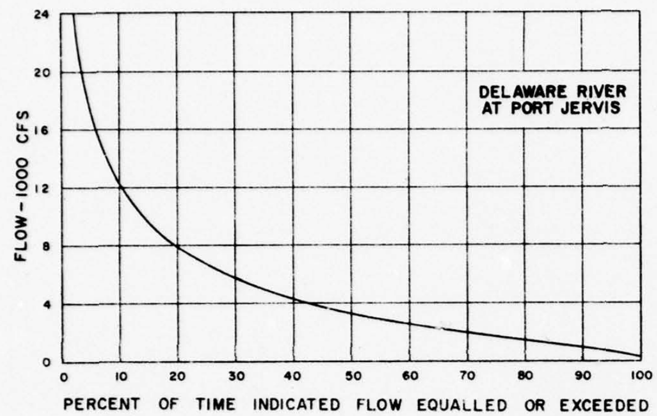
MASS CURVE OF RUNOFF
DELAWARE RIVER AT TRENTON
WATER YEARS 1923 TO 1954

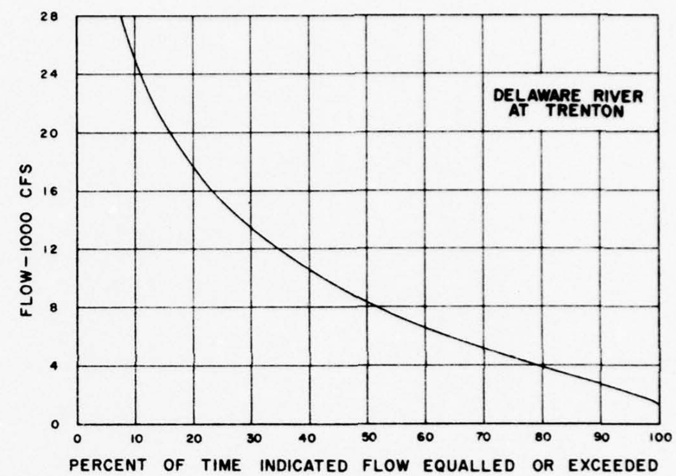
In 1 Sheet	Scales as Shown
Corps of Engineers	Phila. Dist.
Philadelphia, Pa.	30 Nov. 1959
Drawer No. 228	File No. 29006

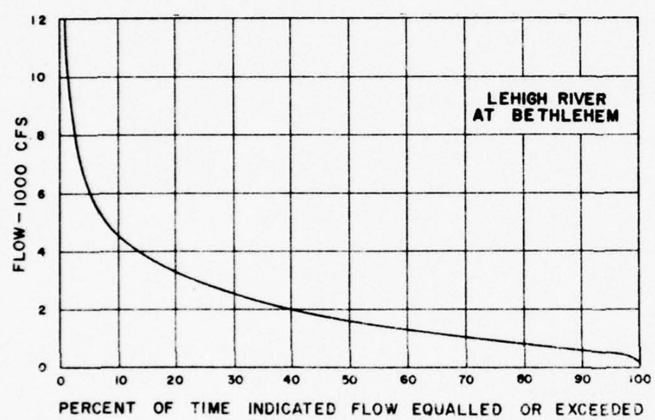
PLATE NO. 31

CORPS OF ENGINEERS

U.S. ARMY







Note:
Daily flow duration data
compiled by U.S. Geological Survey

REVIEW REPORT
DELAWARE RIVER BASIN
FLOW-DURATION CURVES
OF MEAN DAILY FLOW

In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scales as Shown
Philadelphia District
December 1958

Drawer No. 228

File No. 29007

CORPS OF ENGINEERS U.S. ARMY

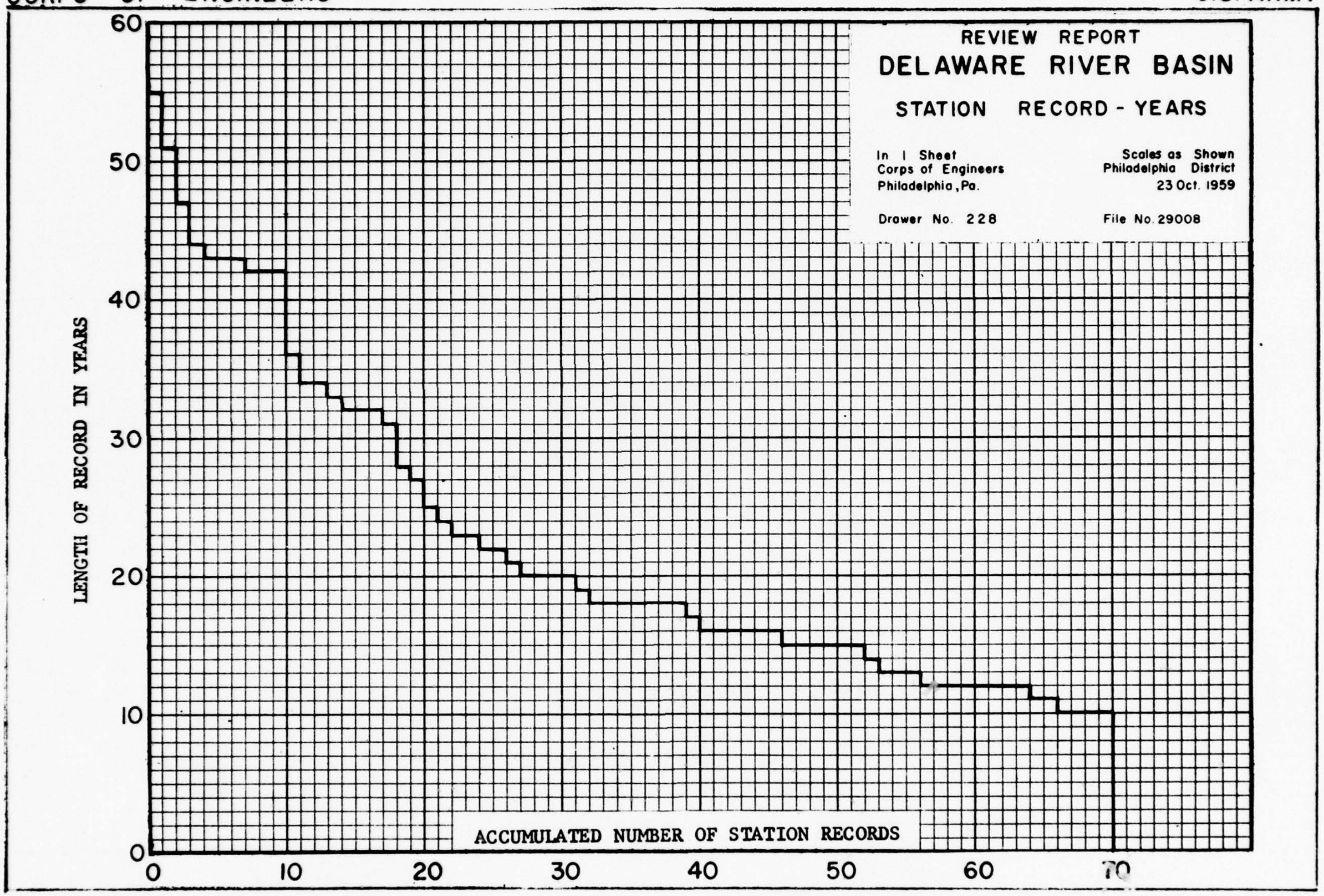


PLATE NO. 33

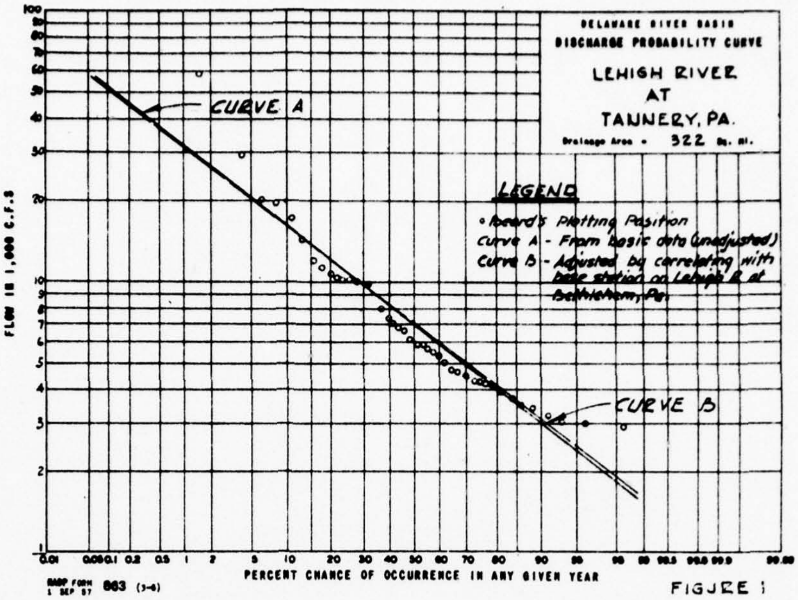


FIGURE 1

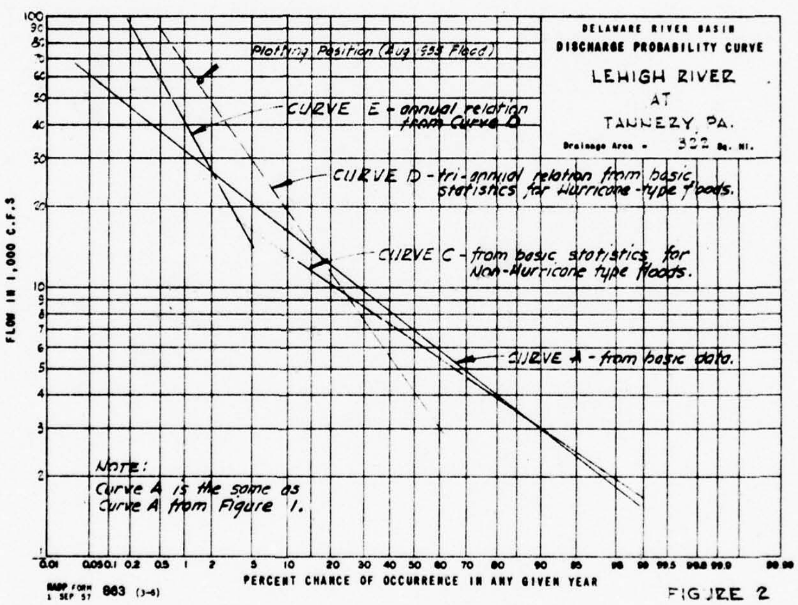


FIGURE 2

REVIEW REPORT
DELAWARE RIVER BASIN

DISCHARGE PROBABILTY

In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scales as Shown
Philadelphia District
10 April 58

Drawer No. 228

File No. 29009

CORPS OF ENGINEERS

U.S. ARMY

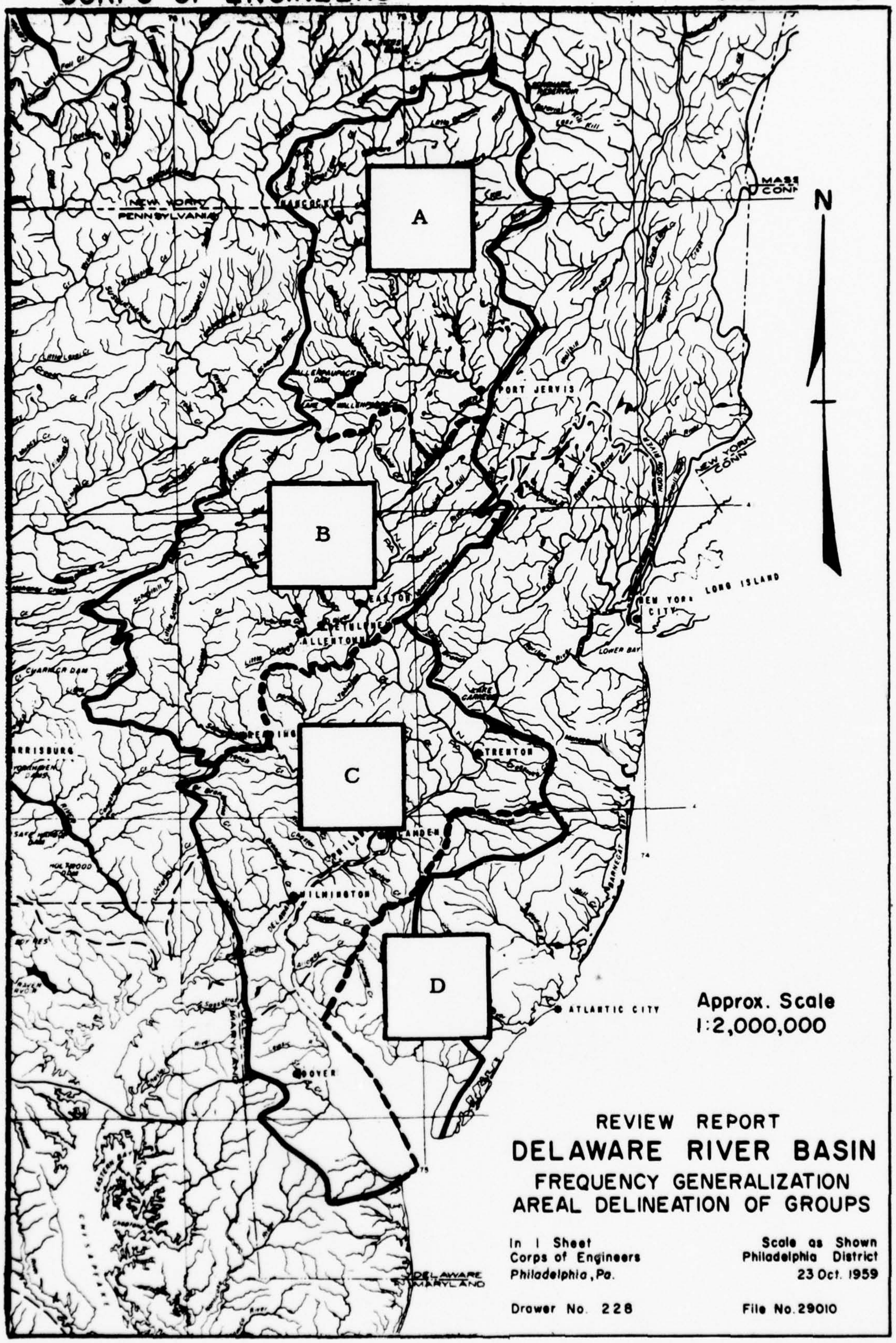
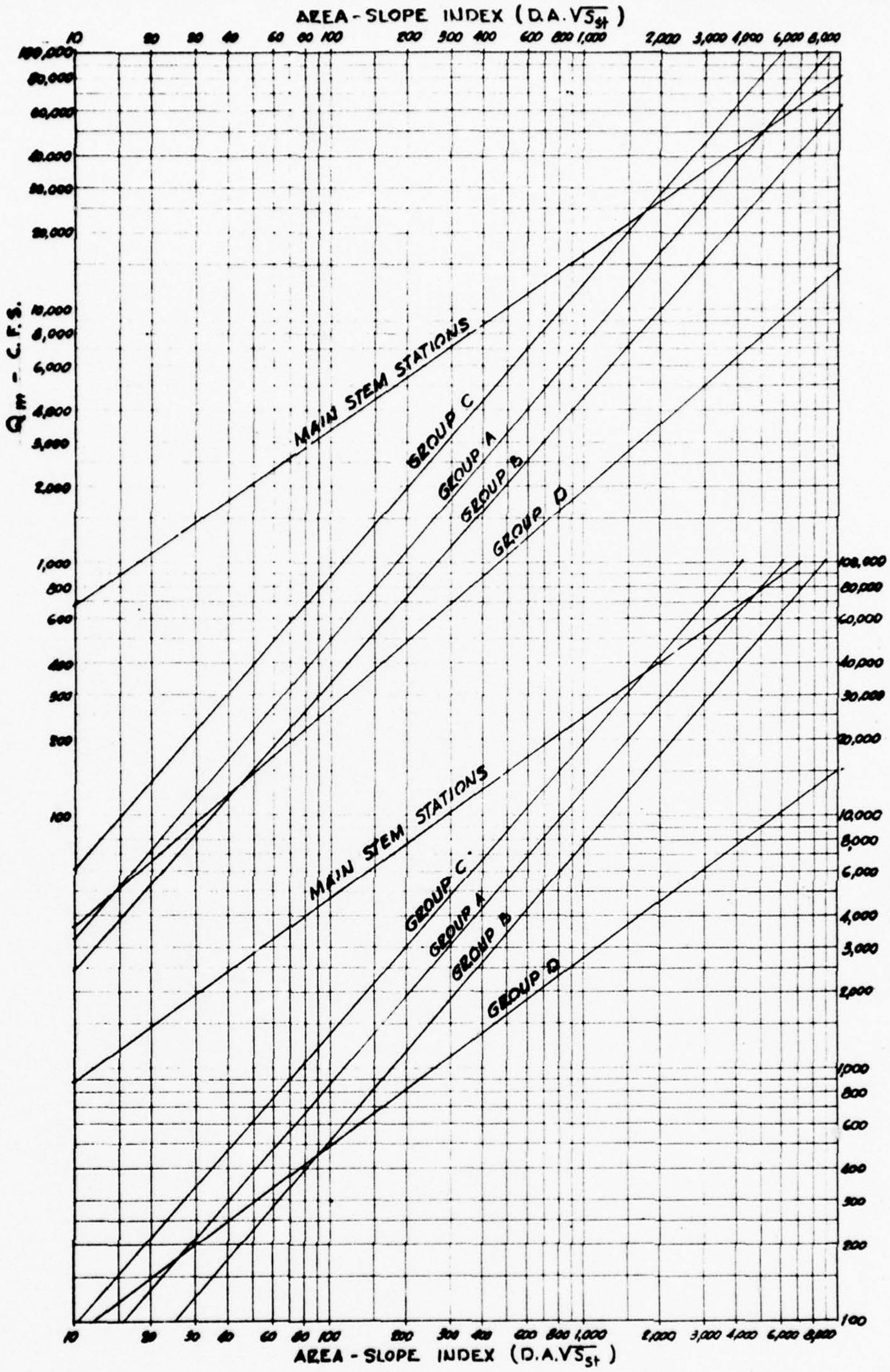


PLATE NO. 35

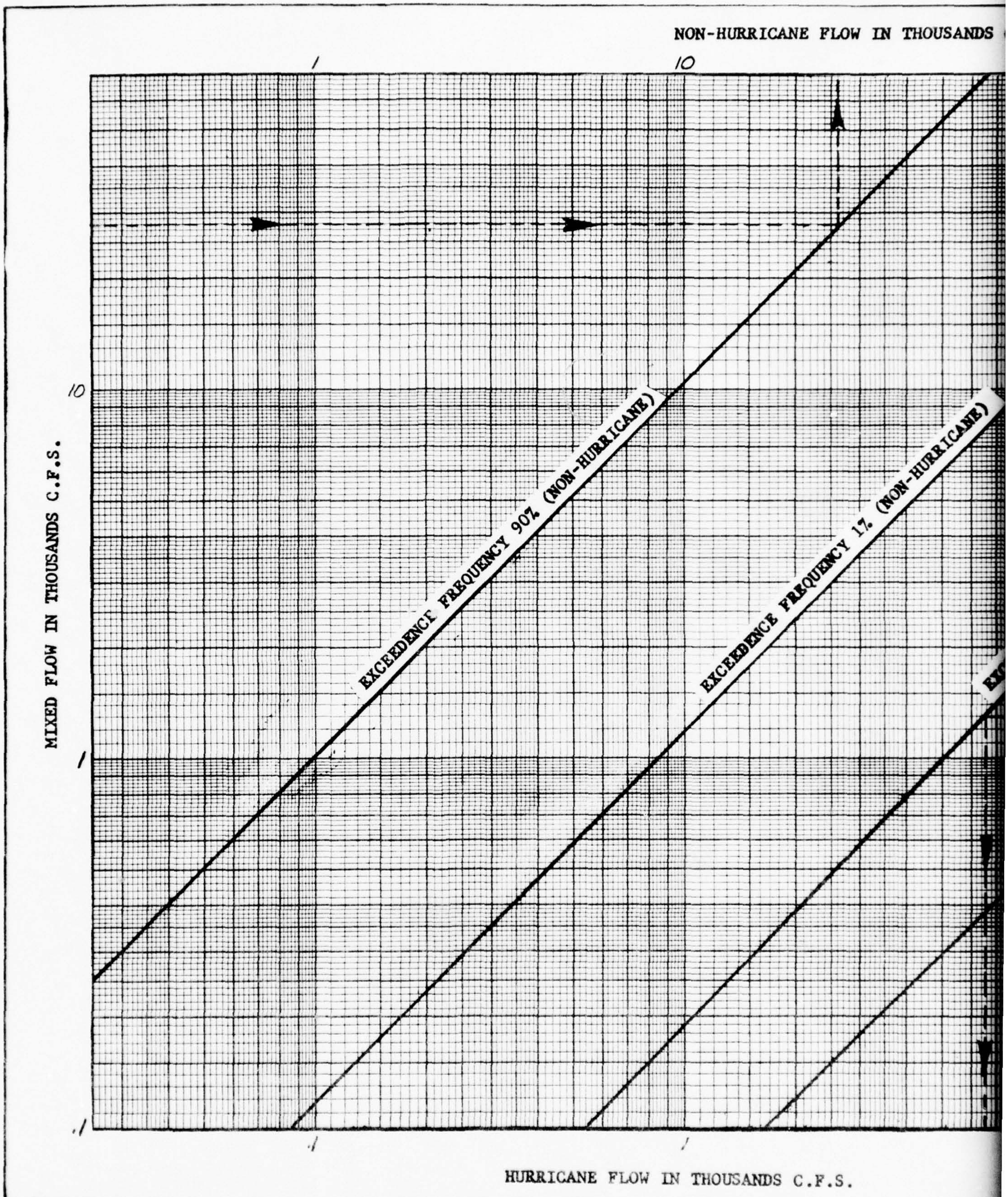


REVIEW REPORT

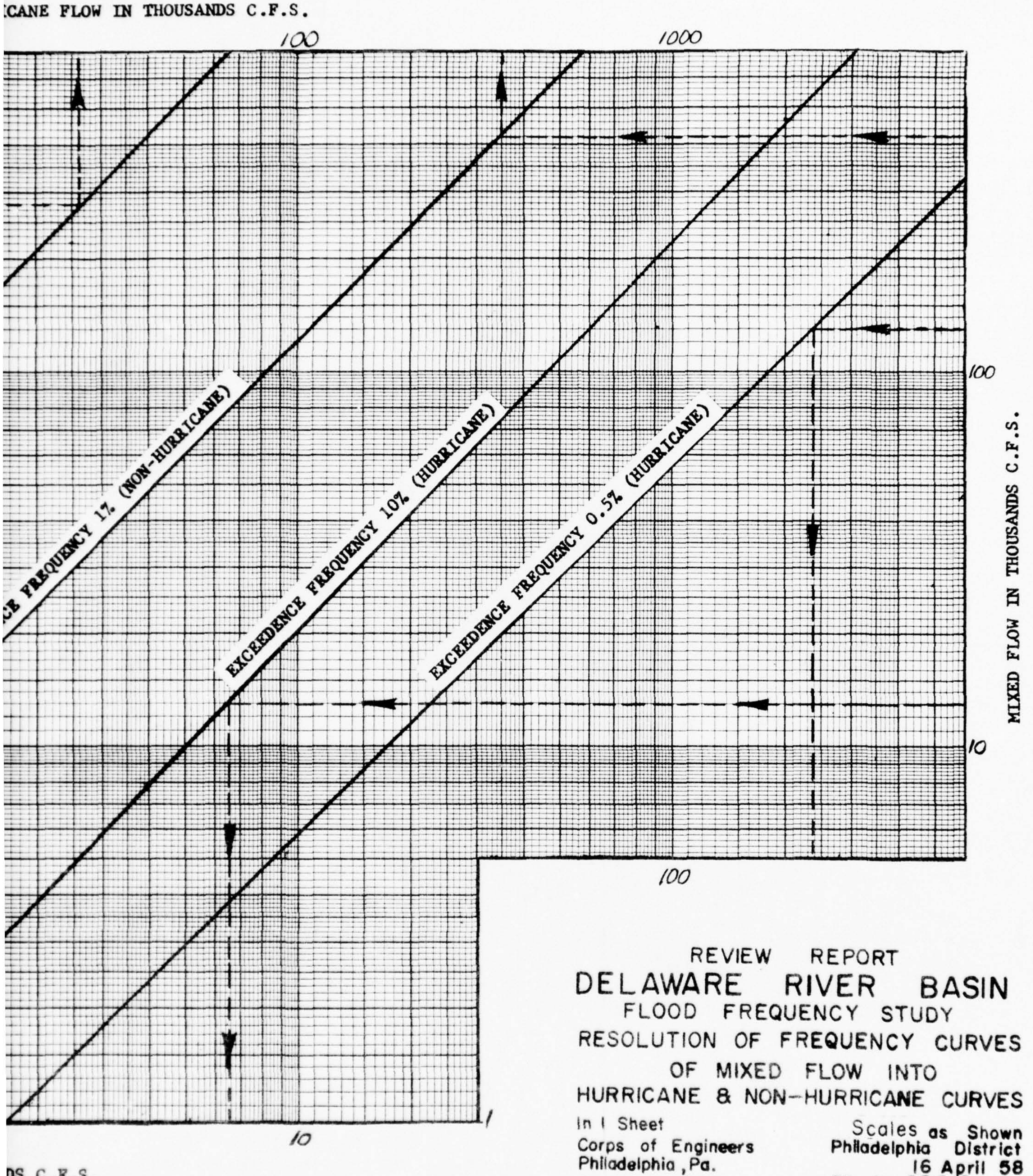
DELAWARE RIVER BASIN

GENERALIZED CURVES - Q_m & Q_{m+s} VERSUS AREA SLOPE INDEX

In 1 Sheet	Scales as Shown
Corps of Engineers	Philadelphia District
Philadelphia, Pa	18 April 58
Drawer No. 228	File No. 29011


NON-HURRICANE FLOW IN THOUSANDS
1
10
10
1
.1
.1
1
MIXED FLOW IN THOUSANDS C.F.S.
EXCEEDENCE FREQUENCY 90% (NON-HURRICANE)
EXCEEDENCE FREQUENCY 1% (NON-HURRICANE)
HURRICANE FLOW IN THOUSANDS C.F.S.

U.S. ARMY



REVIEW REPORT

DELAWARE RIVER BASIN

FLOOD FREQUENCY STUDY

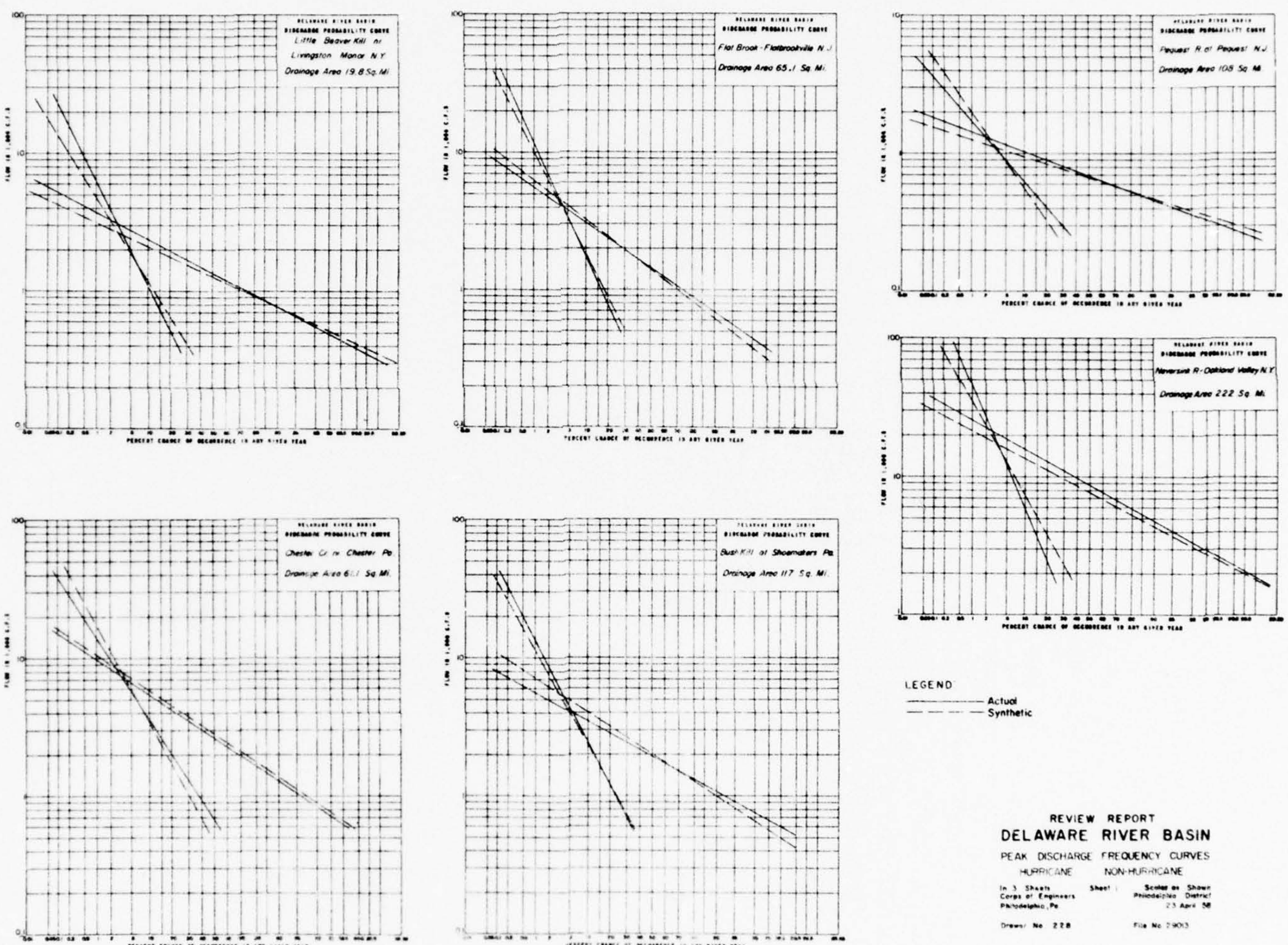
RESOLUTION OF FREQUENCY CURVES OF MIXED FLOW INTO HURRICANE & NON-HURRICANE CURVES

In 1 Sheet	Scales as Shown
Corps of Engineers	Philadelphia District
Philadelphia, Pa.	16 April 58
Drawer No. 228	File No. 29012

PLATE NO. 37

CORPS OF ENGINEERS

U.S. ARMY



LEGEND

——— Actual

— — — Synthetic

REVIEW REPORT

DELAWARE RIVER BASIN

PEAK DISCHARGE FREQUENCY CURVES

HURRICANE NON-HURRICANE

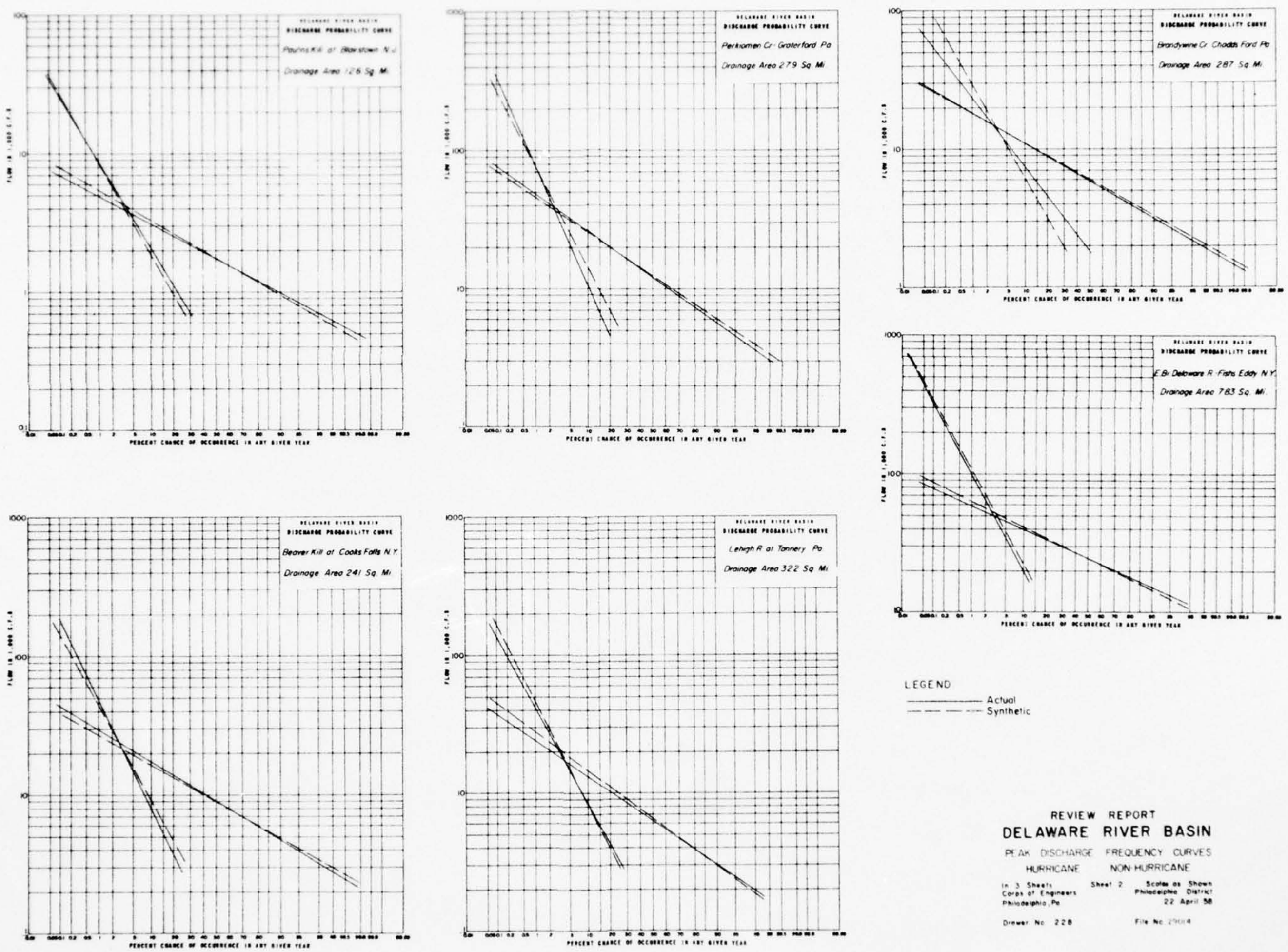
In 3 Sheets Sheet 1 Scales as Shown
Corps of Engineers Philadelphia District
Philadelphia, Pa. 23 April 58

Drawer No. 228 File No. 29013

PLATE NO 38

CORPS OF ENGINEERS

U.S. ARMY



REVIEW REPORT

DELAWARE RIVER BASIN

PEAK DISCHARGE FREQUENCY CURVES

HURRICANE NON-HURRICANE

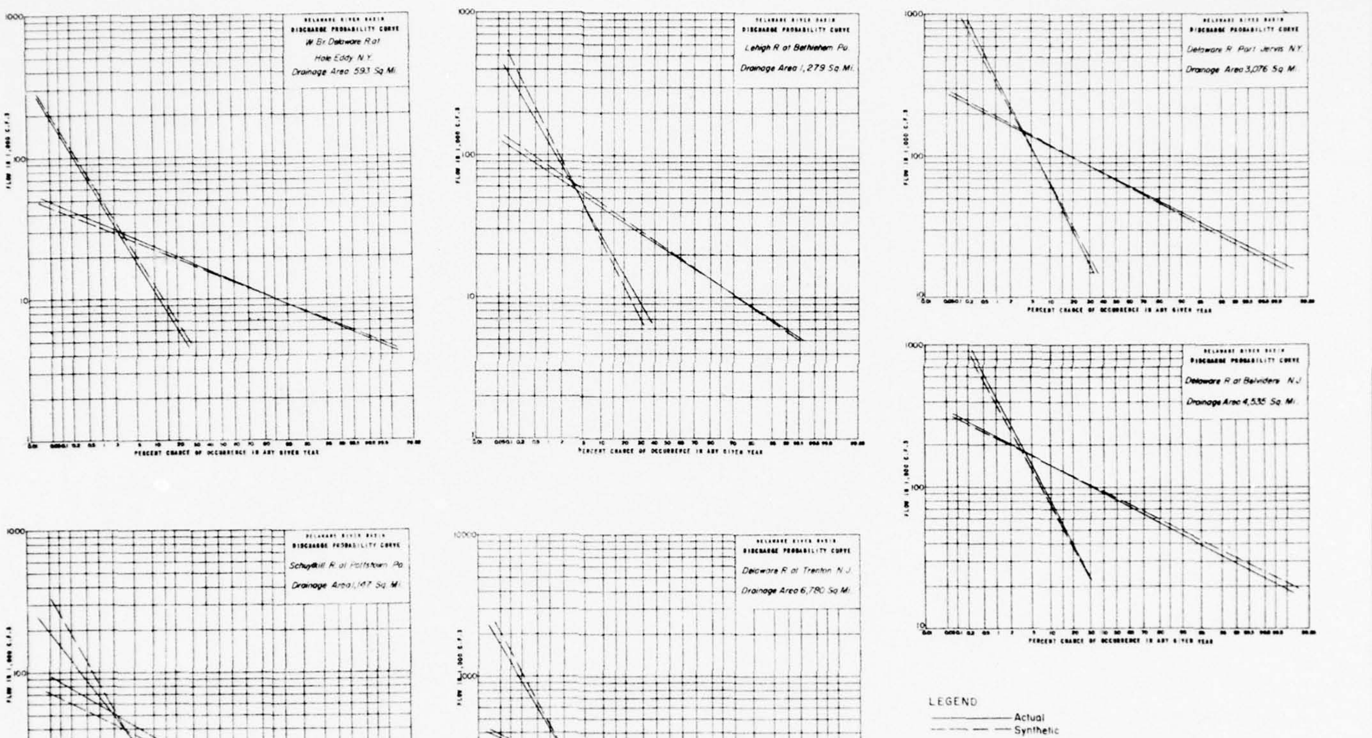
In 3 Sheets Sheet 2 Scales as Shown
Corps of Engineers Philadelphia District
Philadelphia, Pa 22 April 58

Drawer No. 228 File No. 29014

PLATE NO. 39

CORPS OF ENGINEERS

U.S. ARMY



REVIEW REPORT
DELAWARE RIVER BASIN
PEAK DISCHARGE FREQUENCY CURVES
HURRICANE NON-HURRICANE

In 3 Sheets — Sheet 3 — Scales as Shown
Corps of Engineers — Philadelphia District
Philadelphia, Pa. — 22 April 58
Drawer No. 228 — File No. 29015

PLATE NO. 40

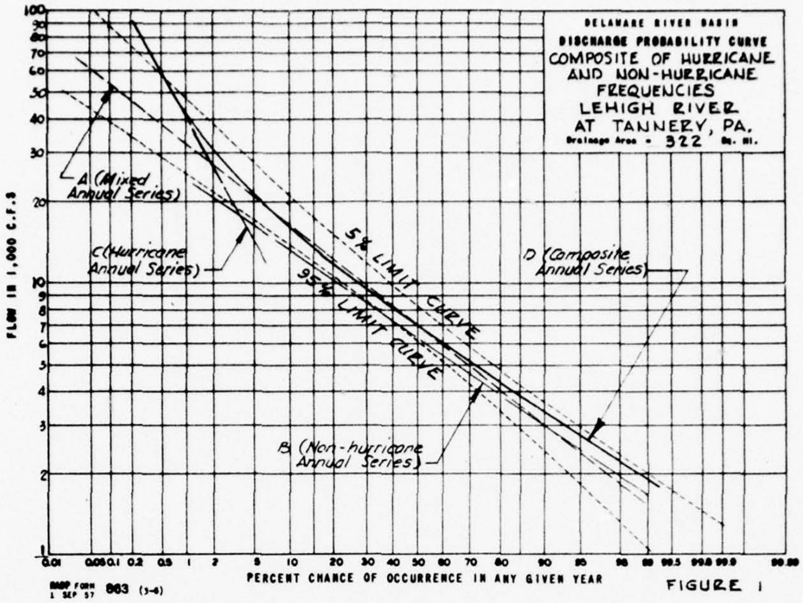


FIGURE 1

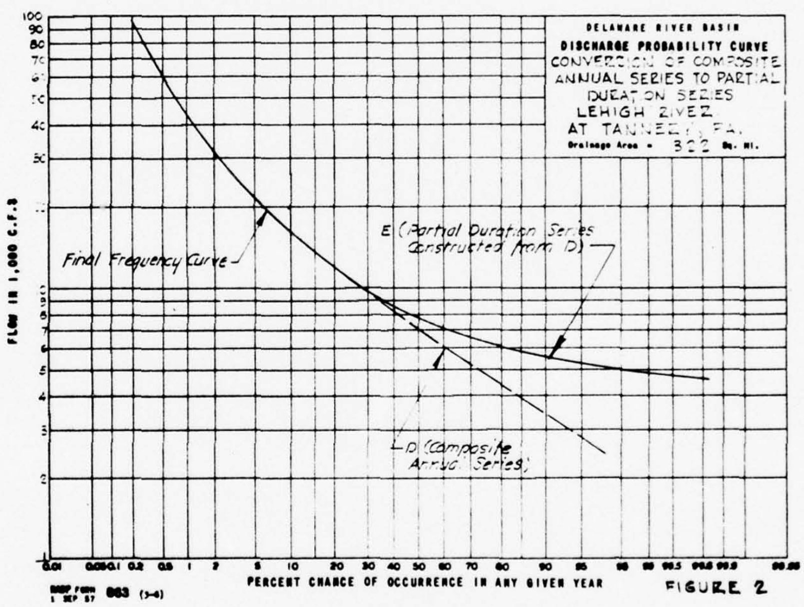


FIGURE 2

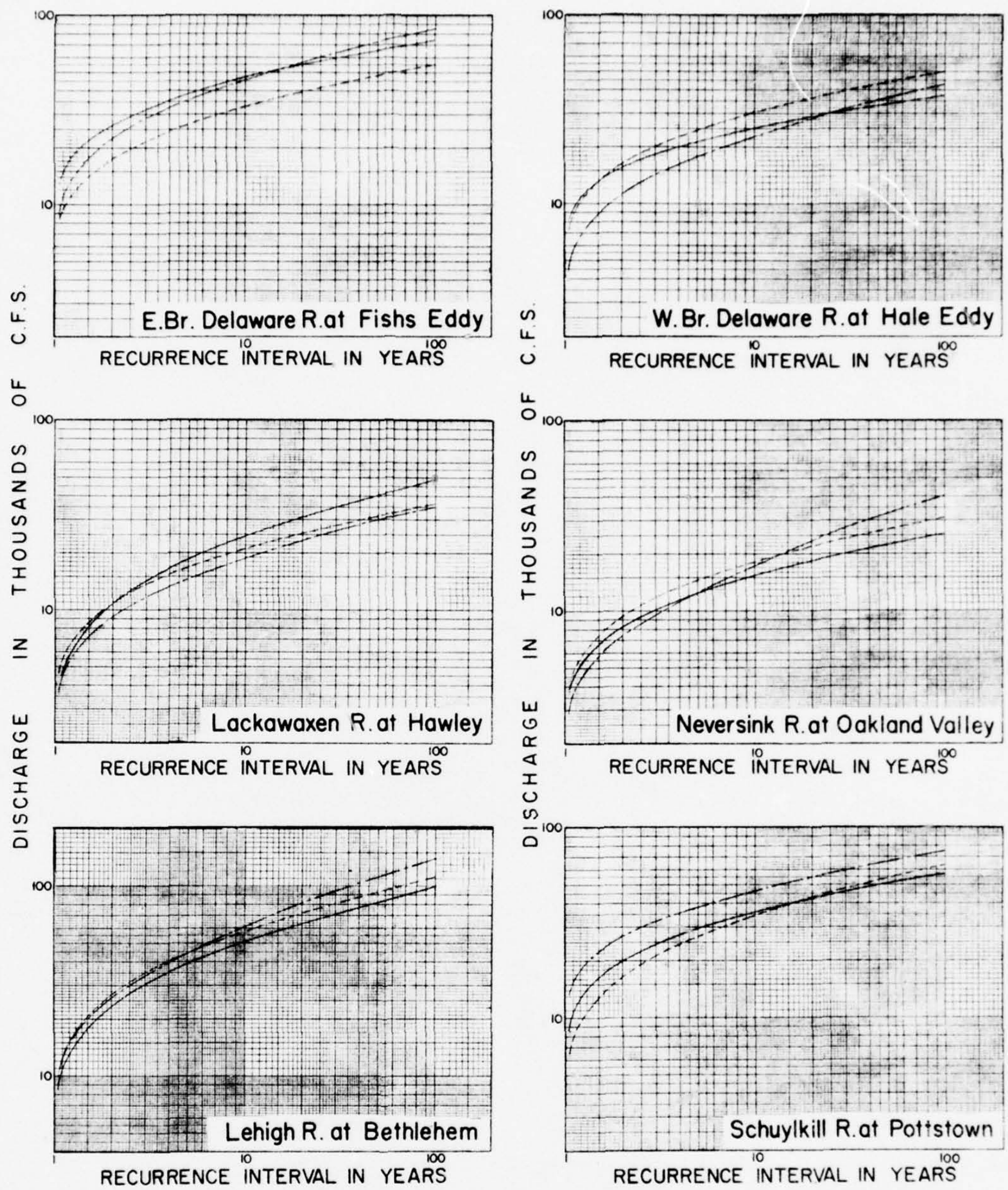
REVIEW REPORT

DELAWARE RIVER BASIN

COMPOSITE & PARTIAL DURATION FREQUENCY CURVES

In 1 Sheet	Scales as Shown
Corps of Engineers	Philadelphia District
Philadelphia, Pa	November 1958
Drawer No 228	File No [illegible]

PLATE NO. 41



LEGEND:

——————— Natural frequency curves based on extended record.

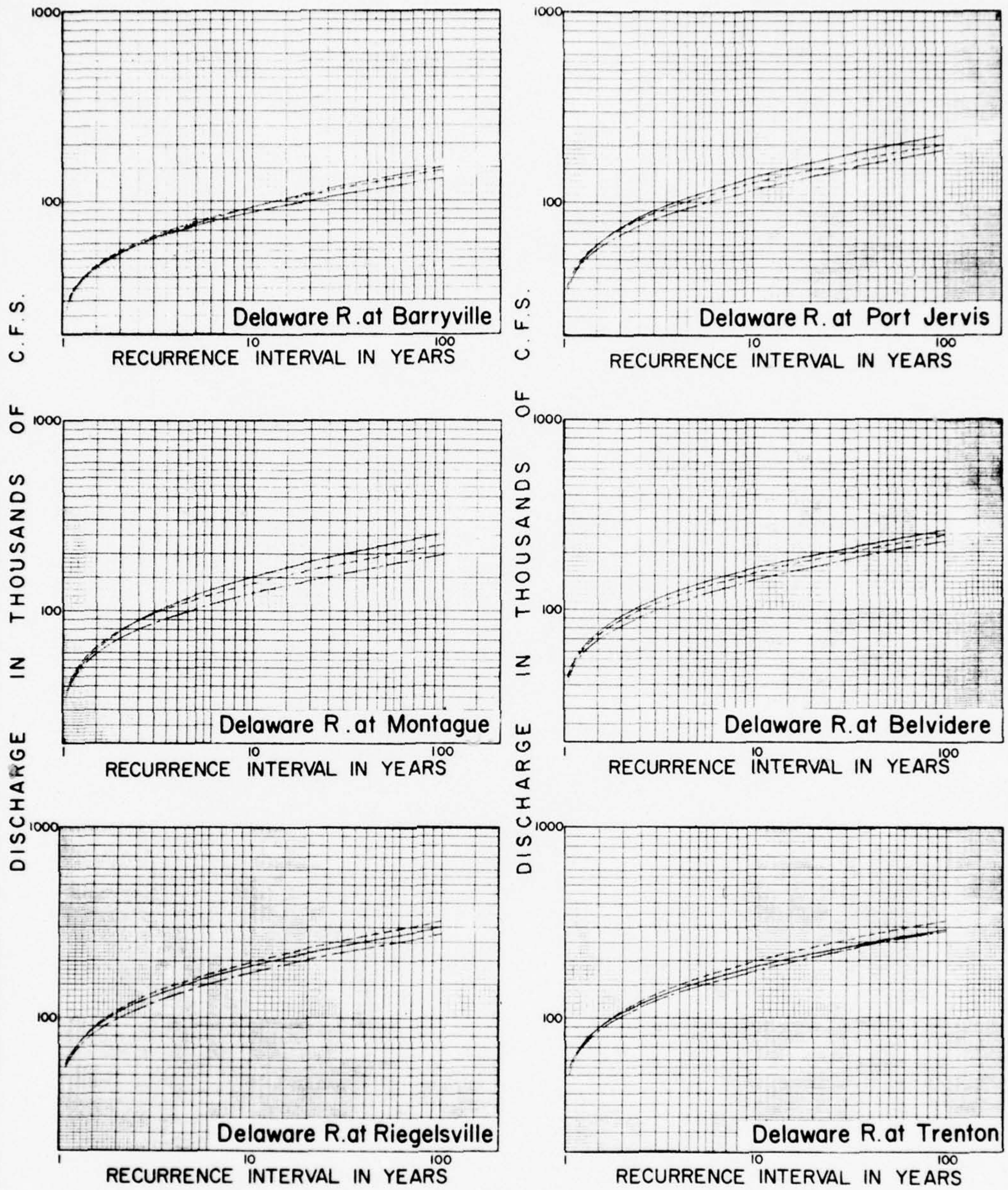
— — — — U.S.G.S. regionalized frequency curves.

———·——— C.E. regionalized frequency curves.

REVIEW REPORT
DELAWARE RIVER BASIN

COMPARISON OF NATURAL FREQUENCY CURVES FROM OBSERVED DATA WITH REGIONALIZED FREQUENCY CURVES OF C. OF E. AND U.S.G.S.

In 2 Sheets	**Sheet I**	**Scales as Shown**
Corps of Engineers		**Philadelphia District**
Philadelphia, Pa.		**January 1959**
Drawer No. 228		**File No. 29017**



LEGEND:

——— Natural frequency curves based on extended record.

– – – – U.S.G.S. regionalized frequency curves.

—·— C.E. regionalized frequency curves.

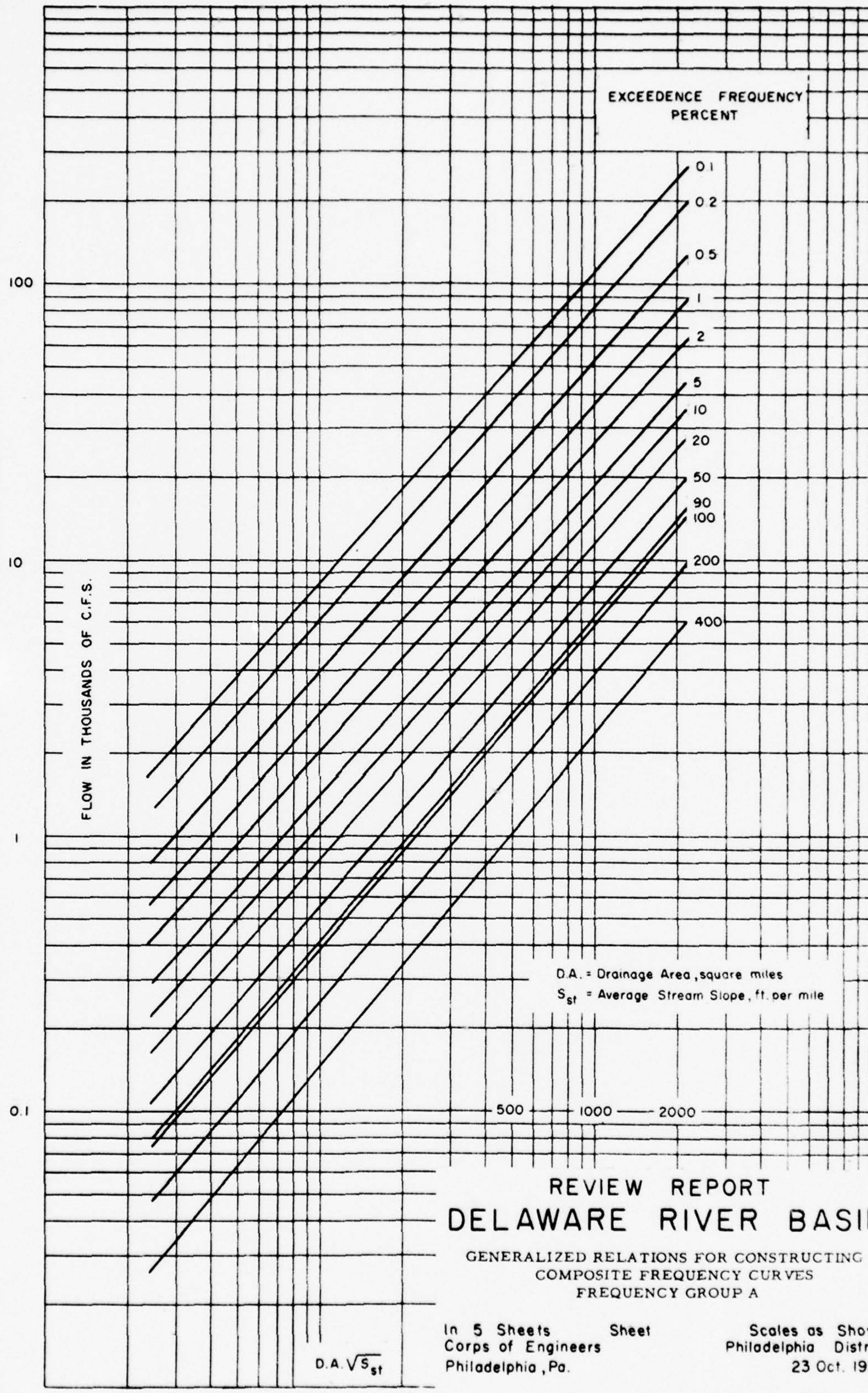
REVIEW REPORT

DELAWARE RIVER BASIN

COMPARISON OF NATURAL FREQUENCY CURVES FROM OBSERVED DATA WITH REGIONALIZED FREQUENCY CURVES OF C. OF E. AND U.S.G.S.

In 2 Sheets | Sheet 2 | Scales as Shown
Corps of Engineers | Philadelphia District
Philadelphia, Pa. | January 1959

Drawer No. 228 | File No. 29018

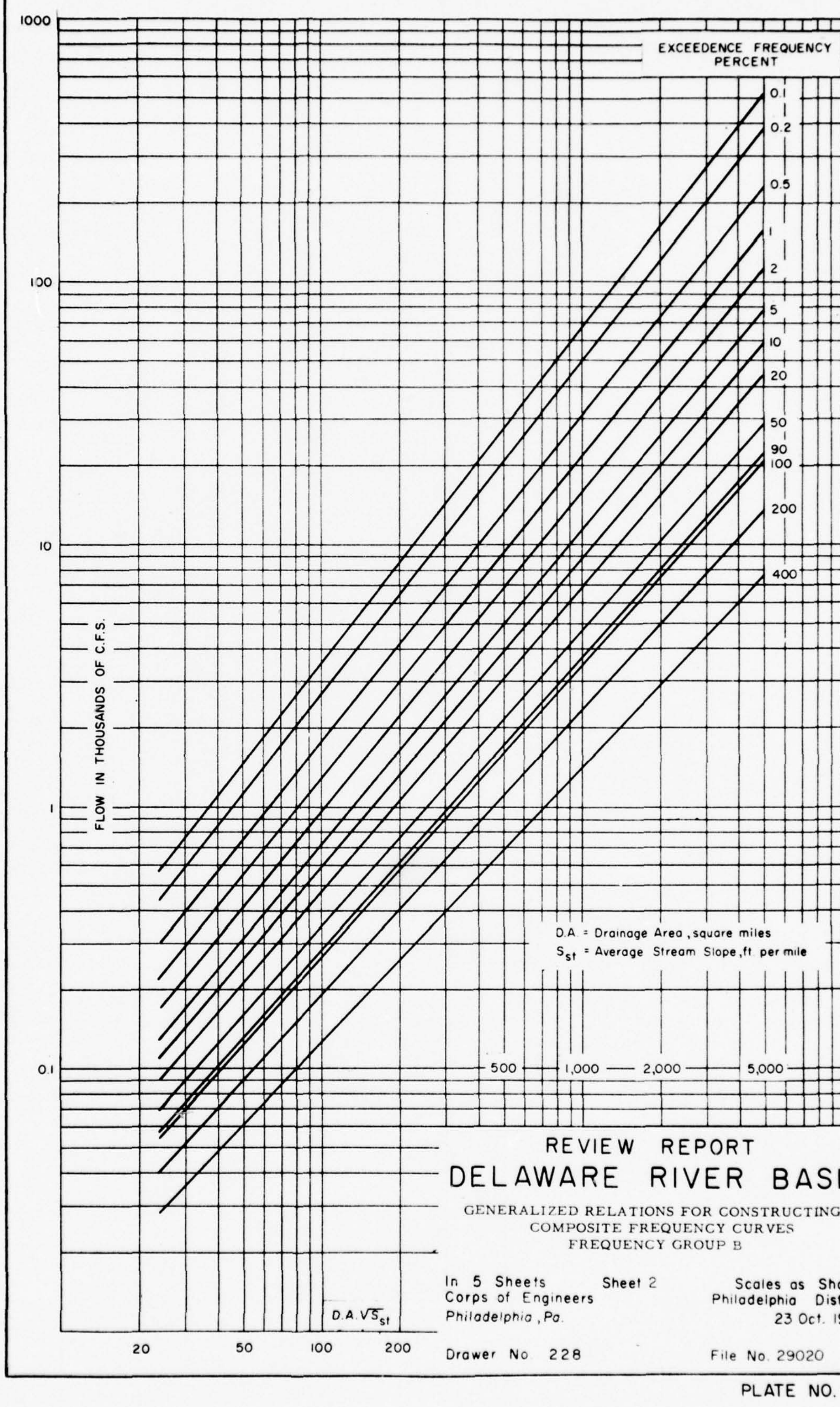


REVIEW REPORT

DELAWARE RIVER BASIN

GENERALIZED RELATIONS FOR CONSTRUCTING COMPOSITE FREQUENCY CURVES
FREQUENCY GROUP A

In 5 Sheets Sheet	Scales as Shown
Corps of Engineers	Philadelphia District
Philadelphia, Pa.	23 Oct. 1959
Drawer No. 228	File No. 29019



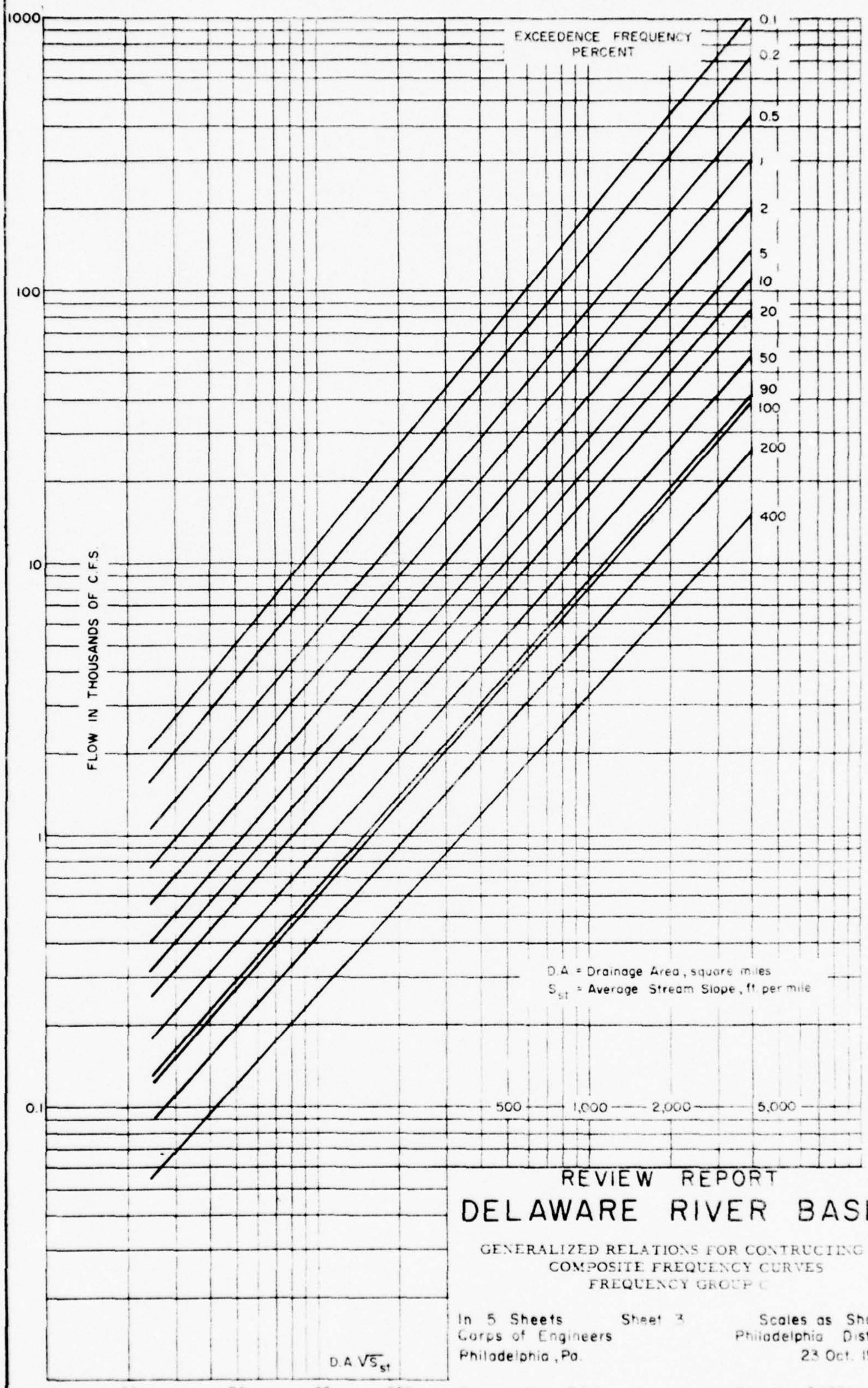
REVIEW REPORT

DELAWARE RIVER BASIN

GENERALIZED RELATIONS FOR CONSTRUCTING COMPOSITE FREQUENCY CURVES FREQUENCY GROUP B

In 5 Sheets Sheet 2 Scales as Shown
Corps of Engineers Philadelphia District
Philadelphia, Pa. 23 Oct. 1959

Drawer No 228 File No. 29020

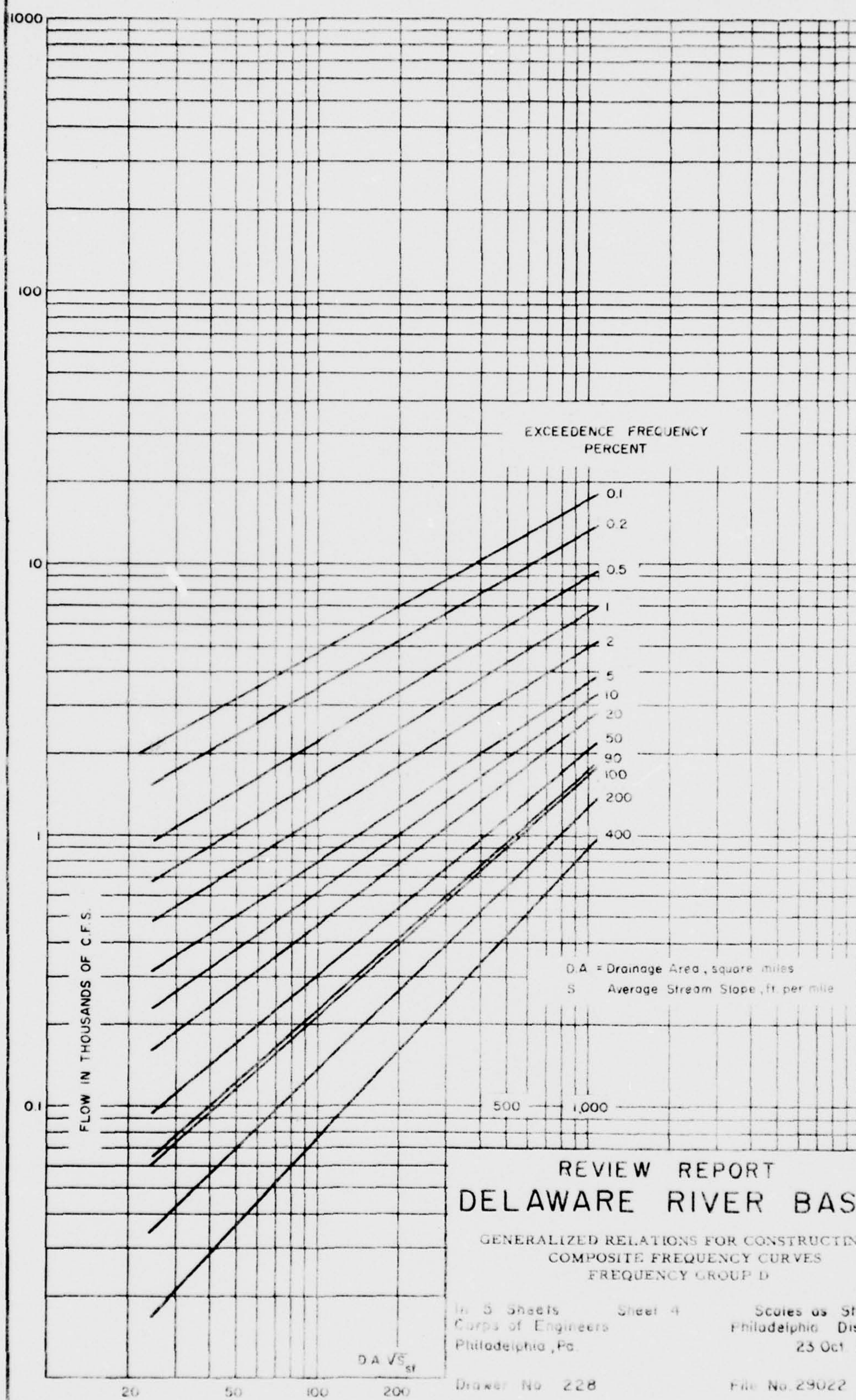


REVIEW REPORT
DELAWARE RIVER BASIN

GENERALIZED RELATIONS FOR CONTRUCTING COMPOSITE FREQUENCY CURVES FREQUENCY GROUP C

In 5 Sheets Sheet 3 Scales as Shown
Corps of Engineers Philadelphia District
Philadelphia, Pa. 23 Oct. 1959

Drawer No. 228 File No. 29021

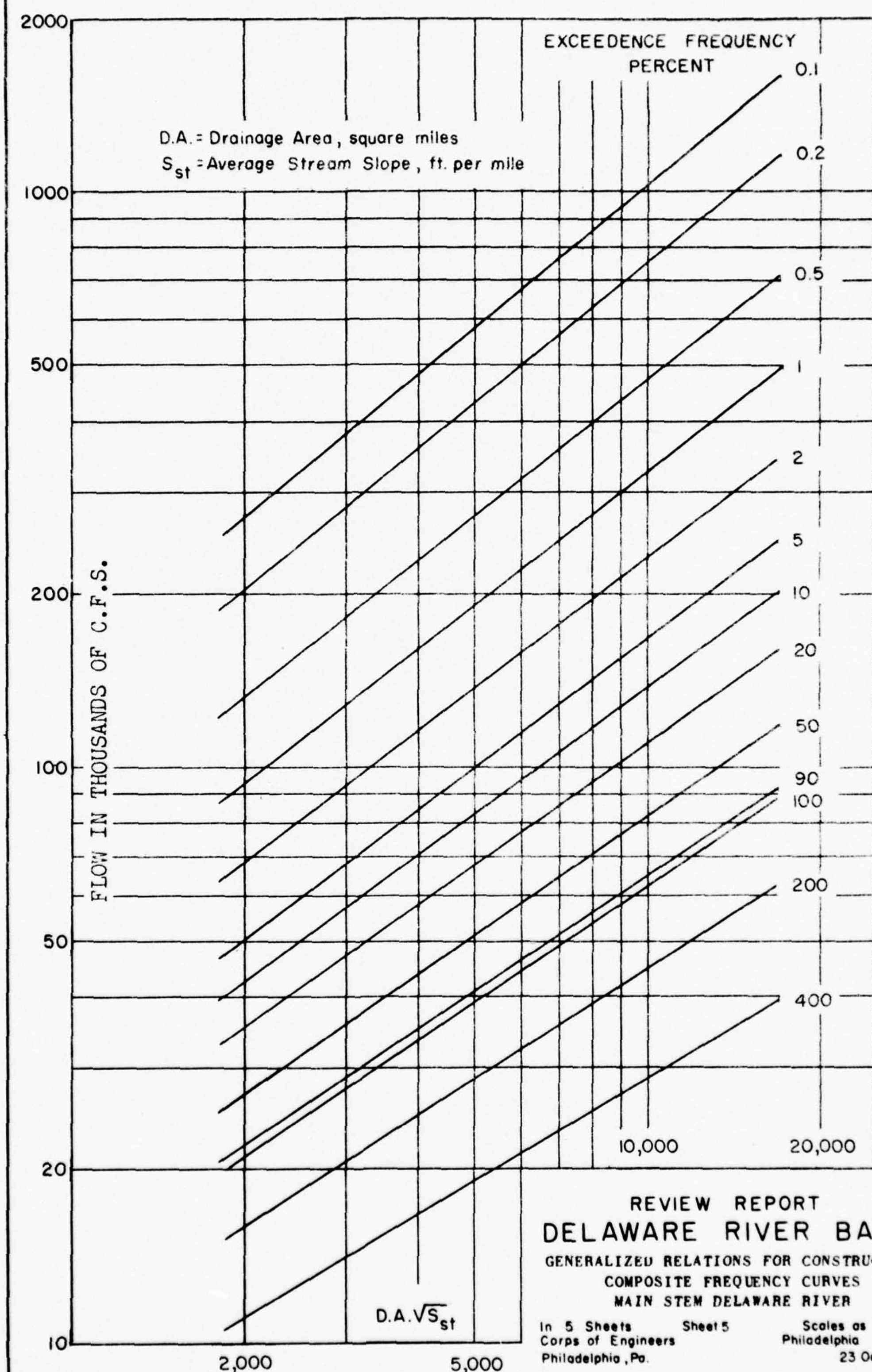


REVIEW REPORT

DELAWARE RIVER BASIN

GENERALIZED RELATIONS FOR CONSTRUCTING
COMPOSITE FREQUENCY CURVES
FREQUENCY GROUP D

In 5 Sheets	Sheet 4	Scales as Shown
Corps of Engineers		Philadelphia District
Philadelphia, Pa.		23 Oct. 1953
Drawer No. 228		File No. 29022



REVIEW REPORT

DELAWARE RIVER BASIN

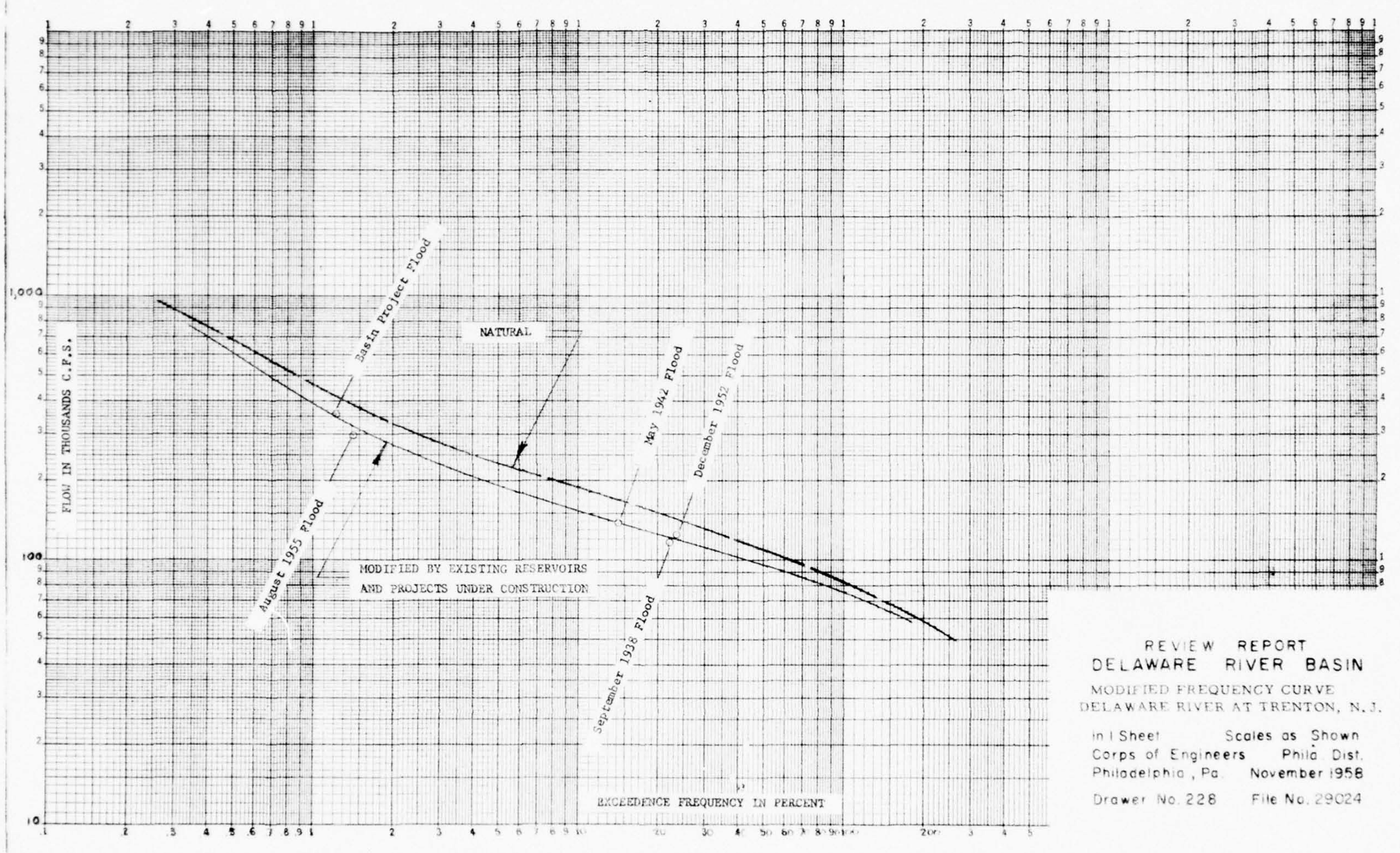
GENERALIZED RELATIONS FOR CONSTRUCTING COMPOSITE FREQUENCY CURVES MAIN STEM DELAWARE RIVER

In 5 Sheets Sheet 5 Scales as Shown
Corps of Engineers Philadelphia District
Philadelphia, Pa. 23 Oct. 1959

Drawer No. 228 File No. 29023

CORPS OF ENGINEERS

U.S. ARMY



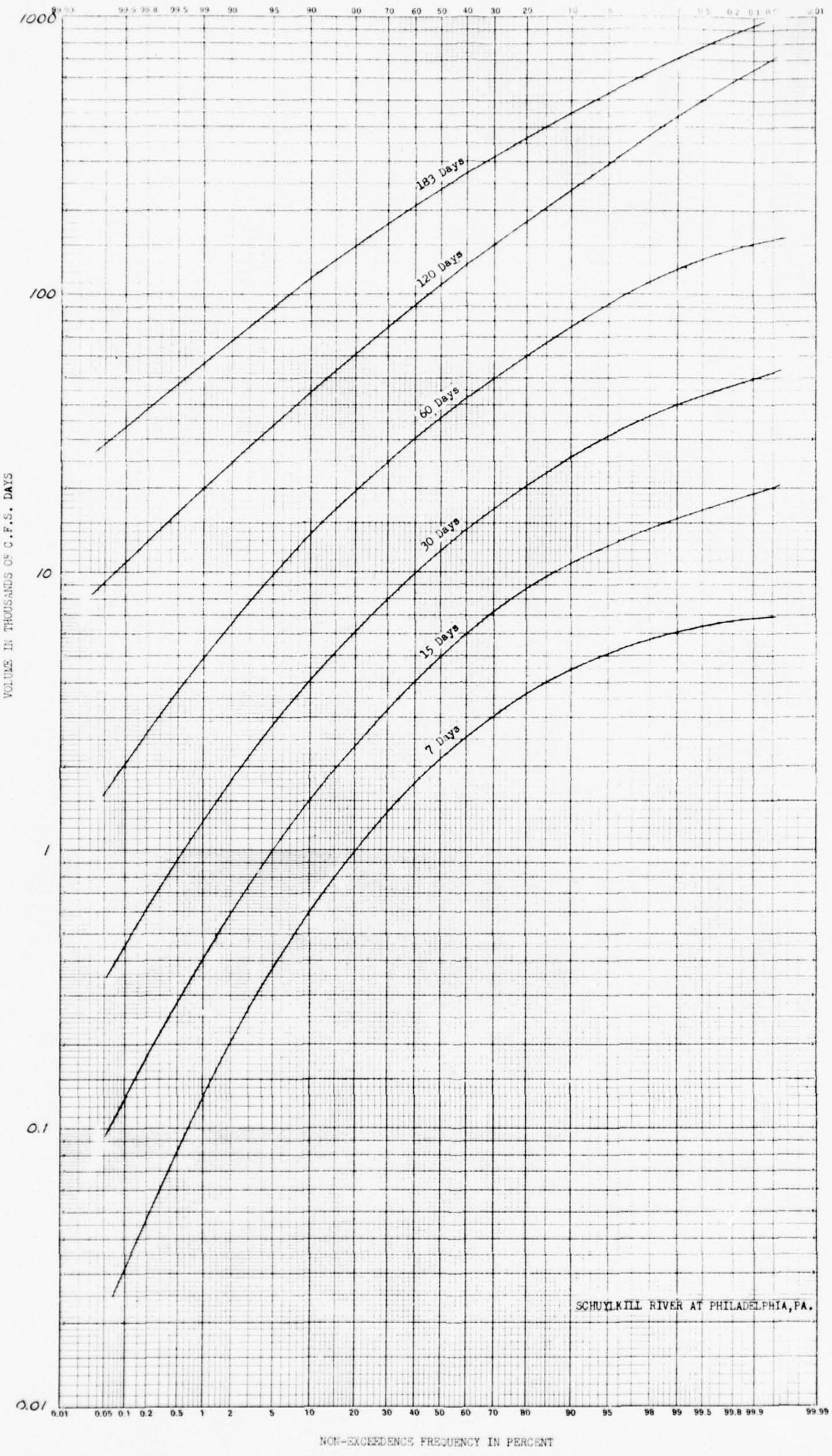
REVIEW REPORT
DELAWARE RIVER BASIN

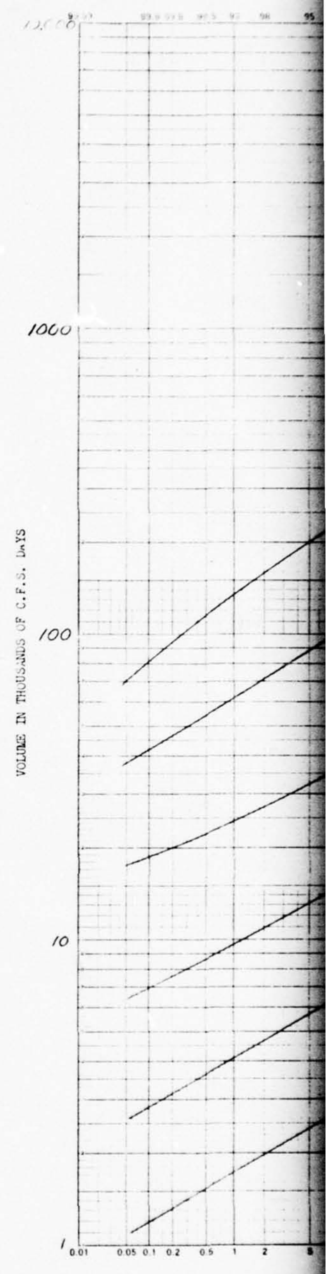
MODIFIED FREQUENCY CURVE
DELAWARE RIVER AT TRENTON, N.J.

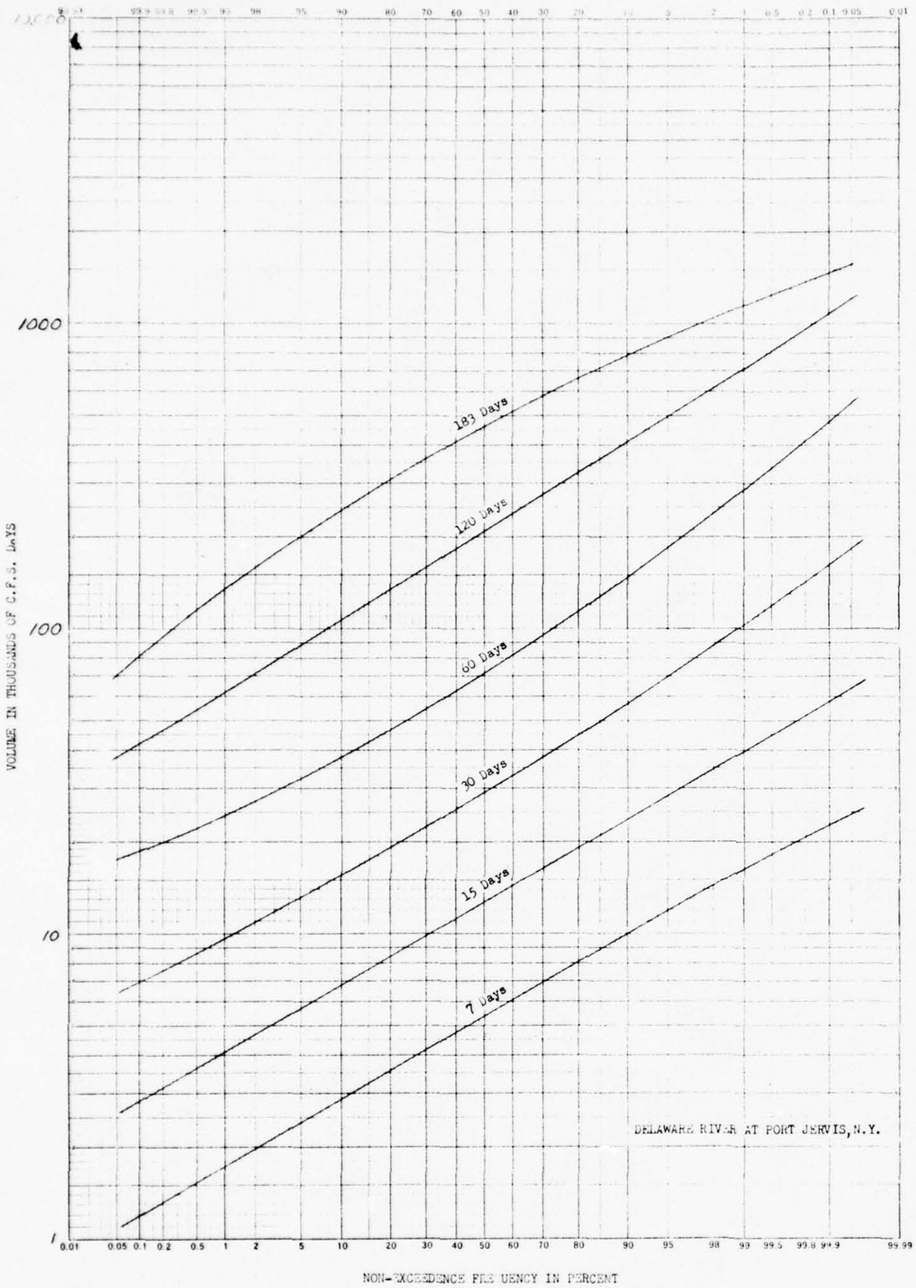
in 1 Sheet — Scales as Shown
Corps of Engineers — Phila. Dist.
Philadelphia, Pa. — November 1958
Drawer No. 228 — File No. 29024

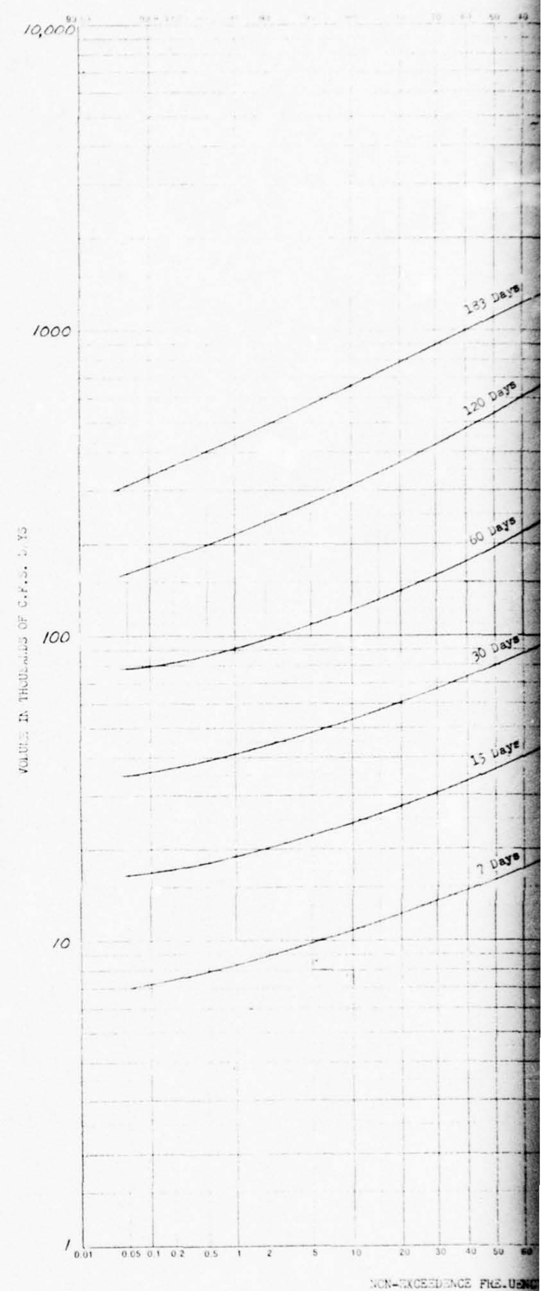
PLATE No. 49

CORPS OF ENGINEERS





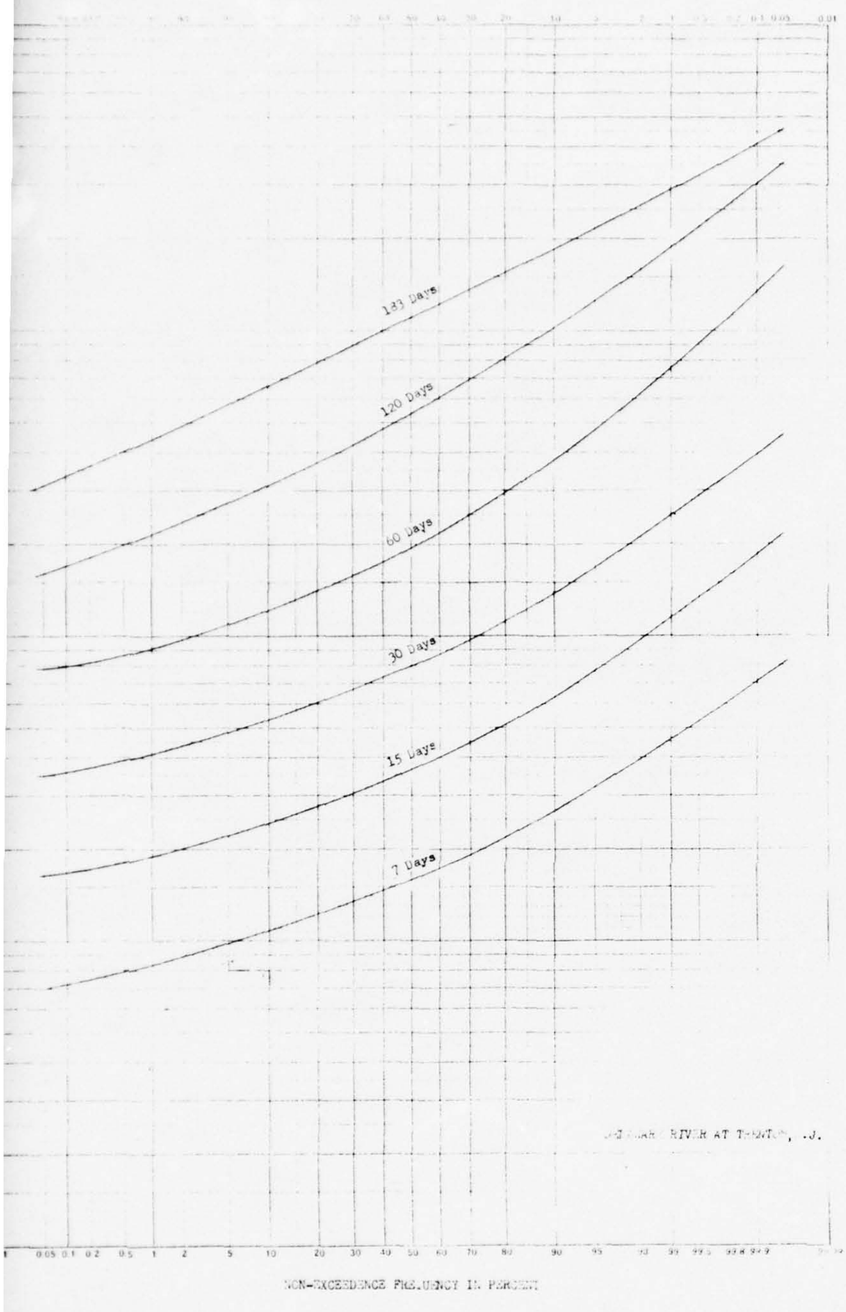




NOTE

NON-EXCEEDENCE FREQUENCY REFERS TO THE PERCENT CHANGE OF OCCURRENCE IN ANY GIVEN YEAR OF A VOLUME EQUAL TO OR LESS THAN THE VALUE INDICATED.

U.S. ARMY



XCEEDENCE FREQUENCY REFERS TO
ERCENT CHANGE OF OCCURRENCE IN
IVEN YEAR OF A VOLUME EQUAL TO
SS THAN THE VALUE INDICATED.

REVIEW REPORT

DELAWARE RIVER BASIN

LOW FLOW VOLUME - DURATION - FREQUENCY CURVES

In 1 Sheet	Scales as Shown
Corps of Engineers	Philadelphia District
Philadelphia, Pa.	January 1959
Drawer No 228	File No 29025

PLATE NO. 50

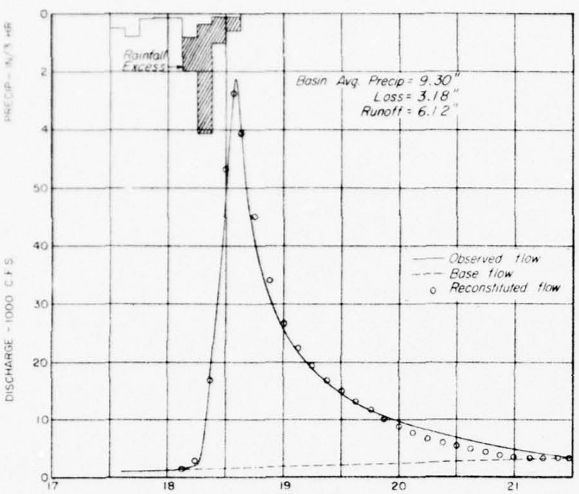


FIGURE 1. FLOOD HYDROGRAPH AND RECONSTITUTION

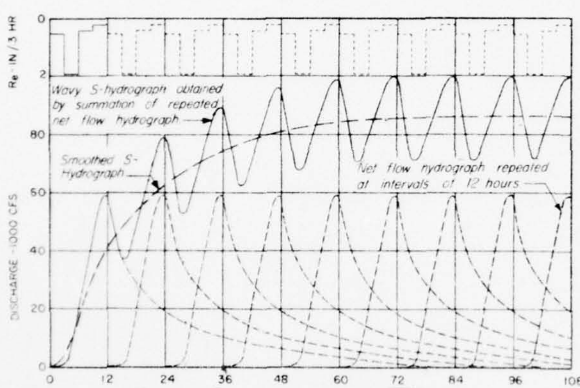


FIGURE 2. CONSTRUCTION OF S-HYDROGRAPH

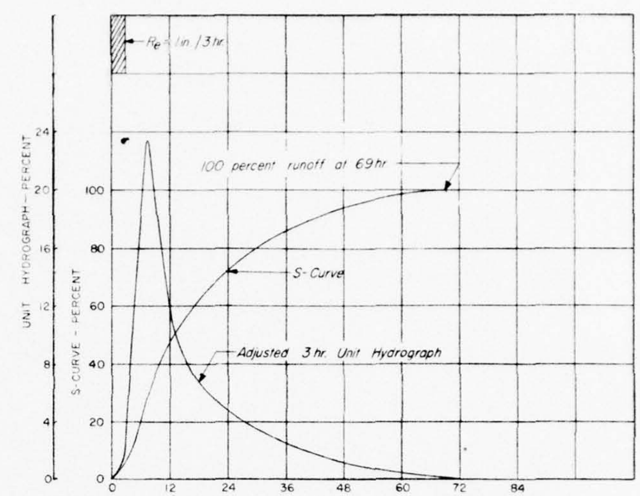


FIGURE 3. S-CURVE AND UNIT HYDROGRAPH

	Start	End	Duration hours
(1) Rainfall Excess	1500 18 Aug	0300 19 Aug	12
(2) Runoff	1500 18 Aug	2400 21 Aug	81
(3) Duration of S-Hydrograph to equilibrium (2)-(1)			69
(4) Duration of 3-hr unit hydrograph (3) + 3 hr.			72

Equilibrium flow = average rainfall excess rate
= 6.12 in./12 hr. = 85,250 c.f.s.

Period of wave in S-hydrograph = rainfall excess duration
= 12 hours

Brodhead Cr. at Minisink Hills, Pa., DA = 259 sq. mi.

Flood of August 1955

REVIEW REPORT

DELAWARE RIVER BASIN

UNIT HYDROGRAPH DERIVATION

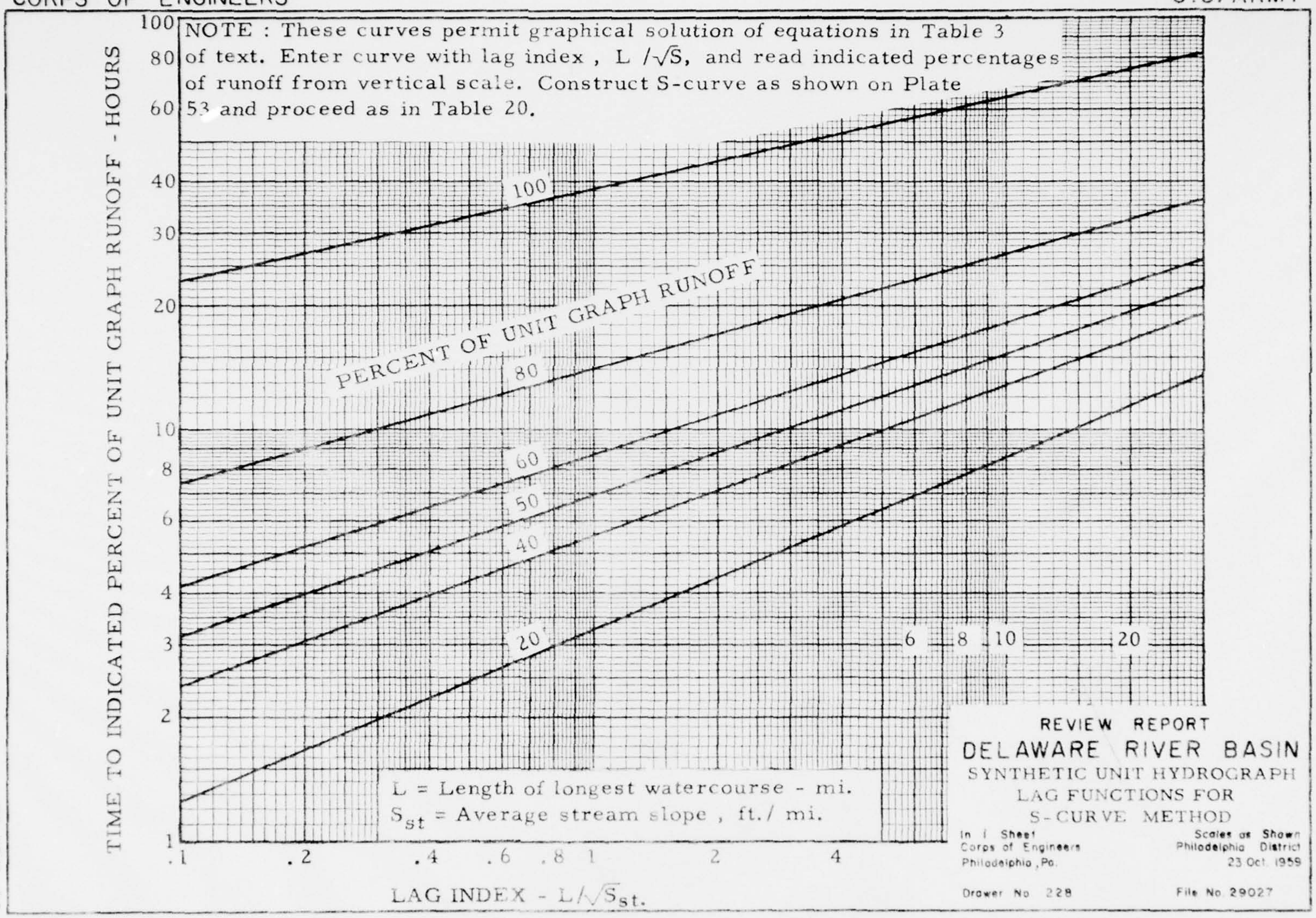
In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scales as Shown
Philadelphia District
23 Oct. 1959

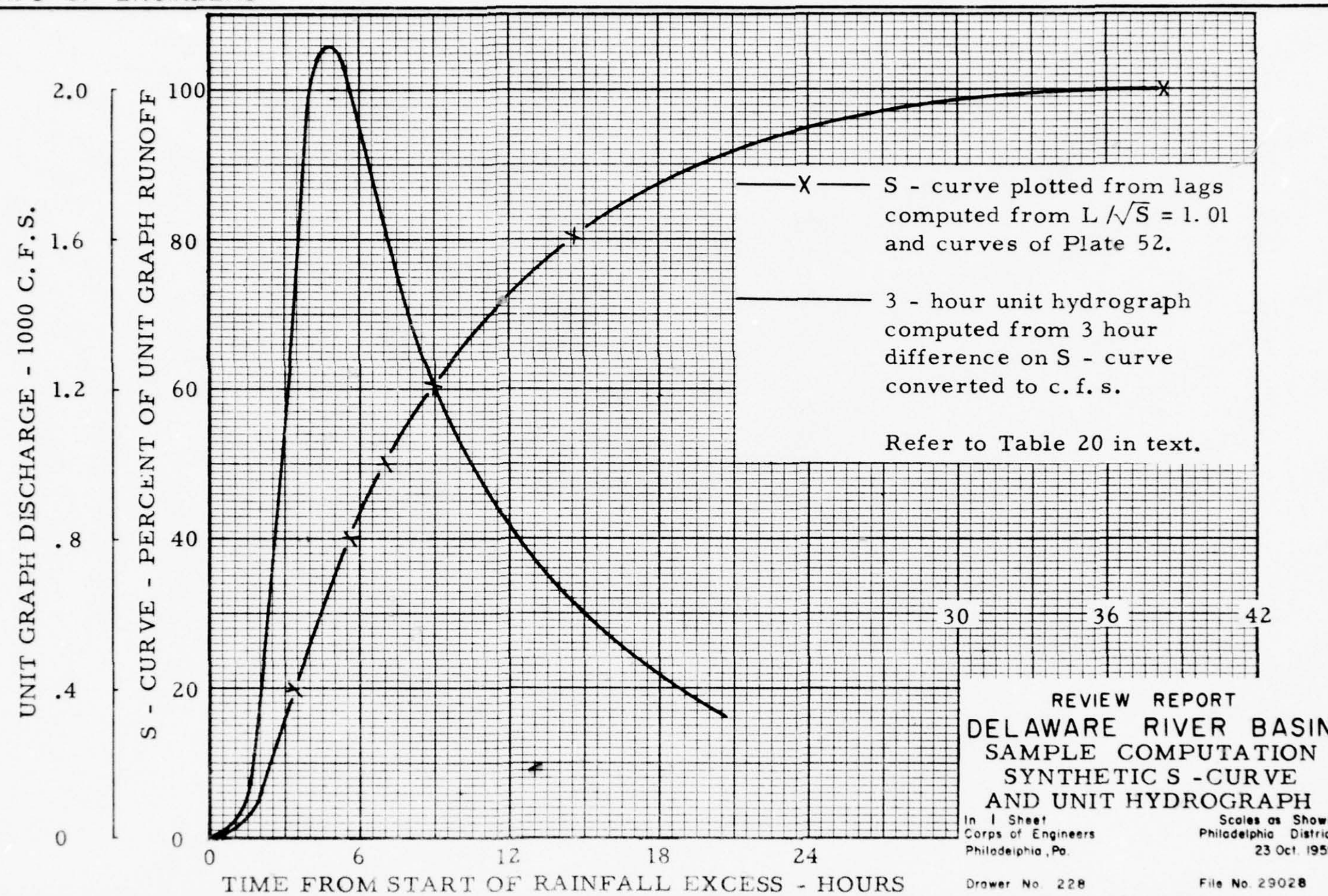
Drawer No. 228

File No. 29026

CORPS OF ENGINEERS U.S. ARMY



CORPS OF ENGINEERS U.S. ARMY



REVIEW REPORT
DELAWARE RIVER BASIN
SAMPLE COMPUTATION
SYNTHETIC S -CURVE
AND UNIT HYDROGRAPH

In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

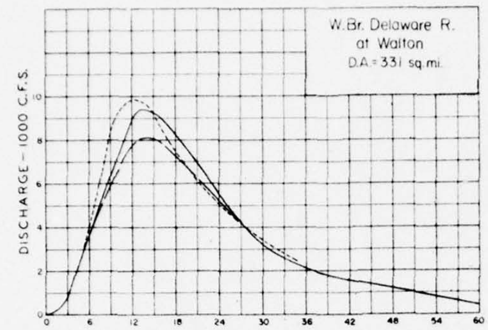
Scales as Shown
Philadelphia District
23 Oct. 1959

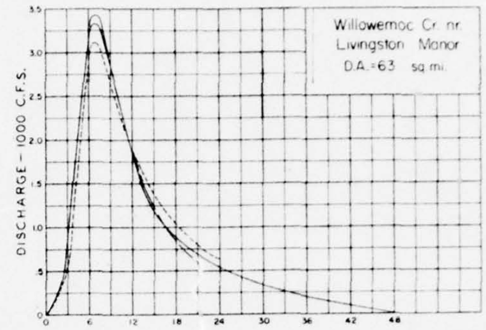
Drawer No. 228

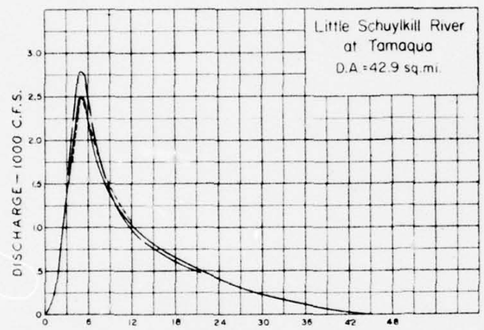
File No. 29028

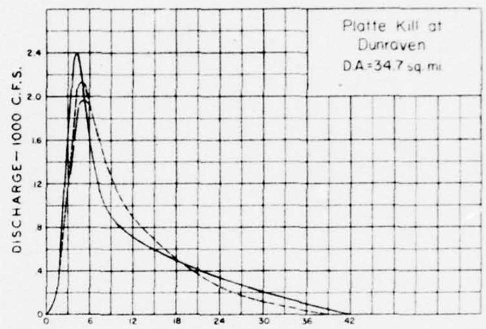
PLATE 53

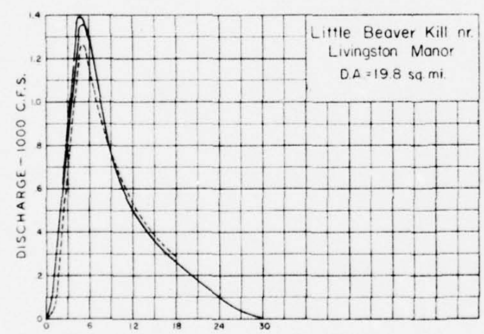
CORPS OF ENGINEERS U.S. ARMY

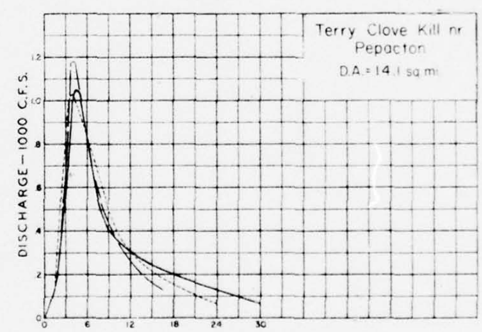


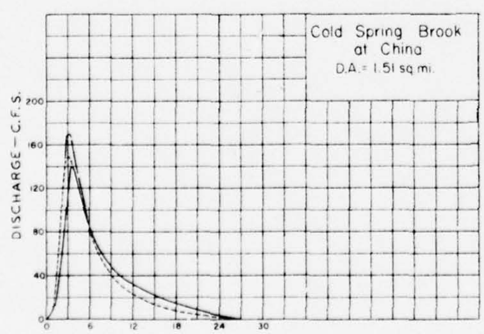












Note: All horizontal scales are time from start of rainfall excess in hours.

——— Derived
— — Taylor - Schwarz synthetic
------ S-Curve synthetic

REVIEW REPORT

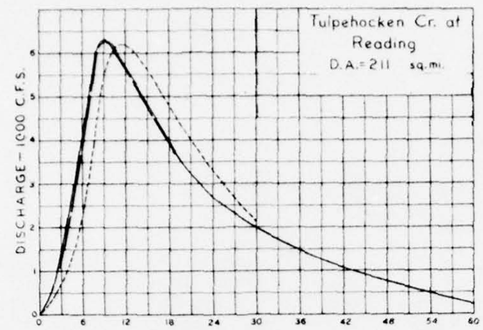
DELAWARE RIVER BASIN

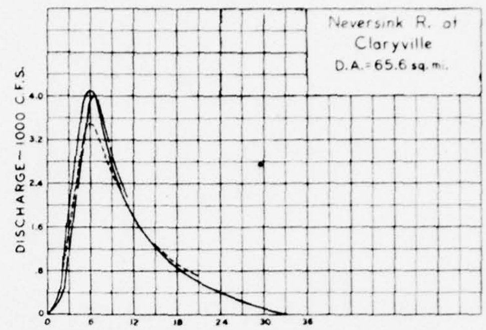
DERIVED AND SYNTHETIC 3 — HOUR UNIT HYDROGRAPHS

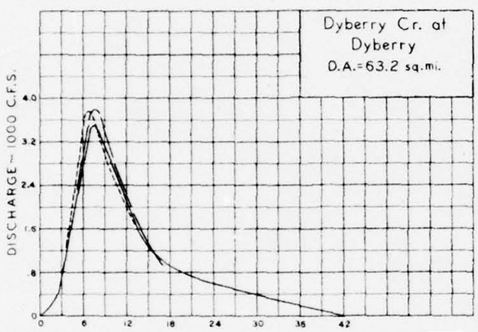
In 2 Sheets	Sheet 1	Scales as Shown
Corps of Engineers		Philadelphia District
Philadelphia, Pa.		28 May 58

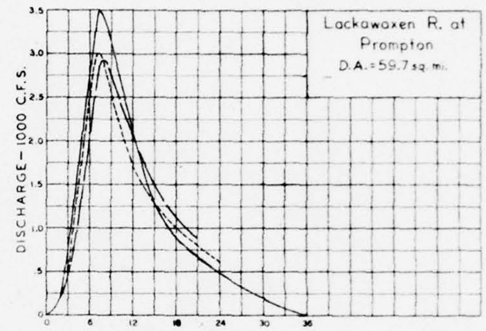
Drawer No. 316 File No. 29029

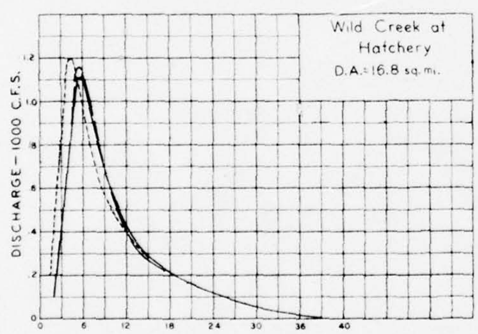
CORPS OF ENGINEERS U. S. ARMY

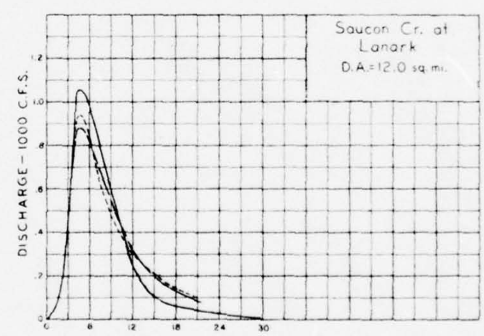


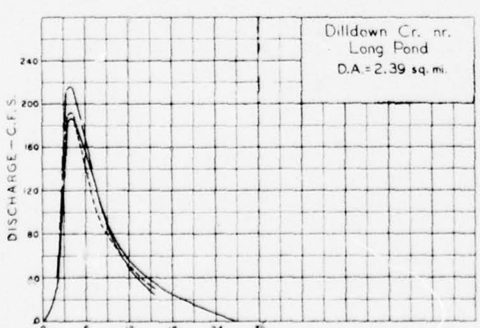












Note: All horizontal scales are time from start of rainfall excess in hours.

- ——— Derived
- — — Taylor — Schwarz synthetic
- ------ S-Curve synthetic

REVIEW REPORT

DELAWARE RIVER BASIN

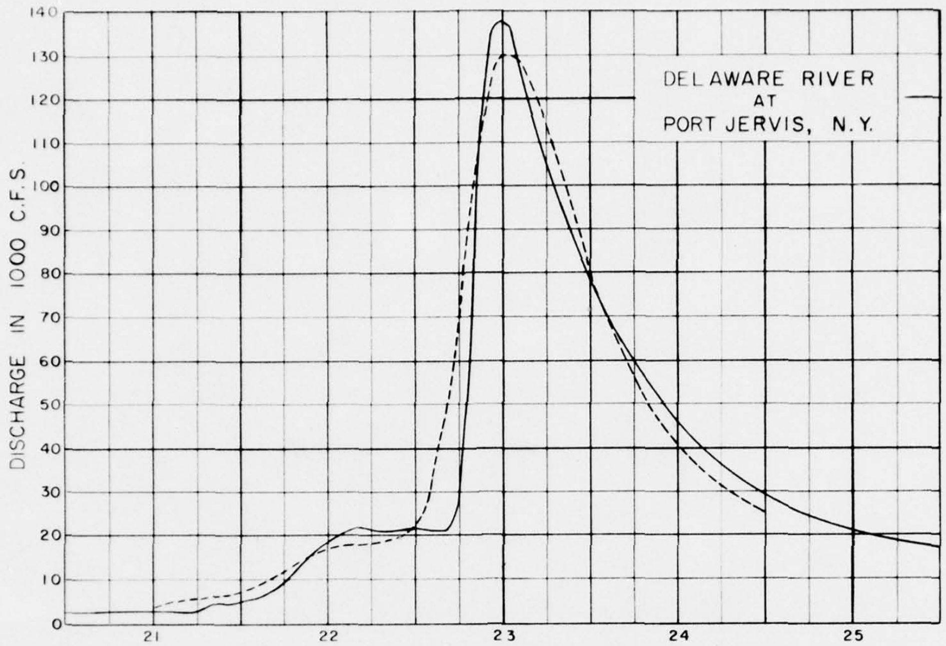
DERIVED AND SYNTHETIC 3 — HOUR UNIT HYDROGRAPHS

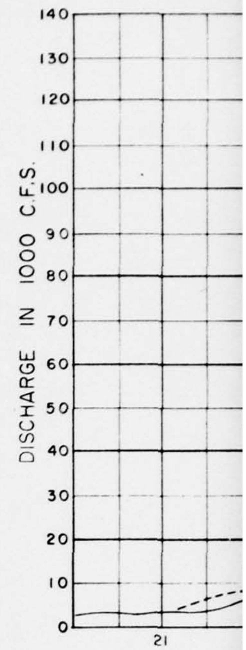
In 2 Sheets Sheet 2 Scales as Shown
Corps of Engineers Philadelphia District
Philadelphia, Pa. 28 May 58

Drawer No. 316 File No. 29030

PLATE NO. 55

F


DELAWARE RIVER
AT
PORT JERVIS, N.Y.
DISCHARGE IN 1000 C.F.S.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
21
22
23
24
25


DISCHARGE IN 1000 C.F.S.
0
10
20
30
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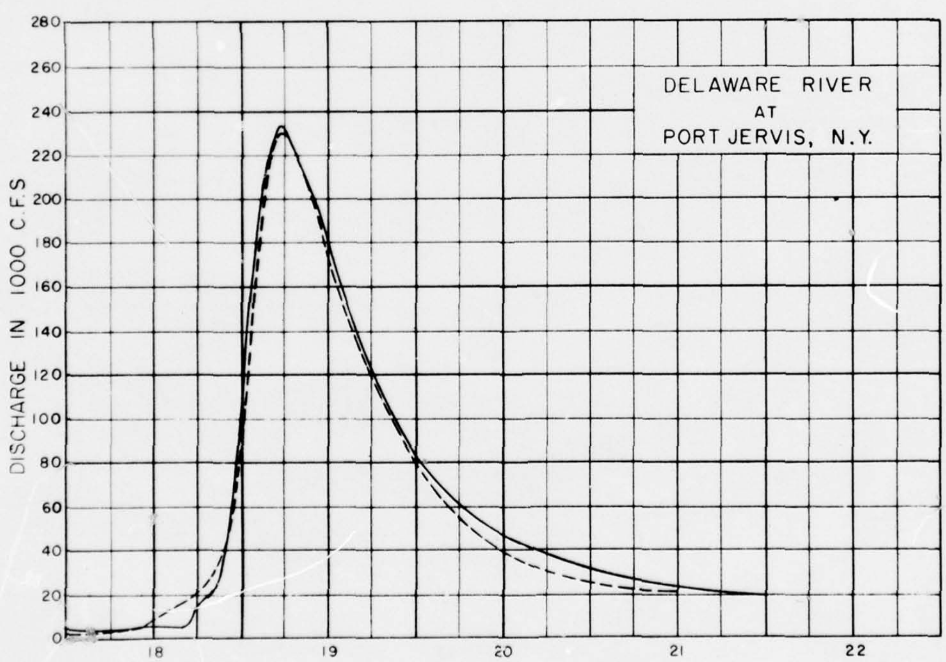
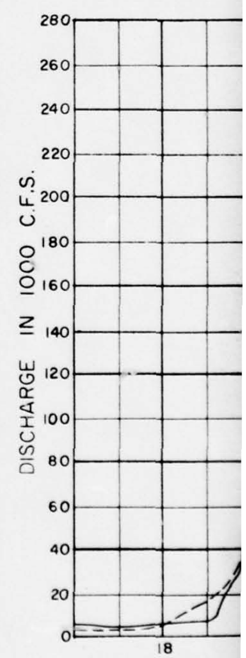
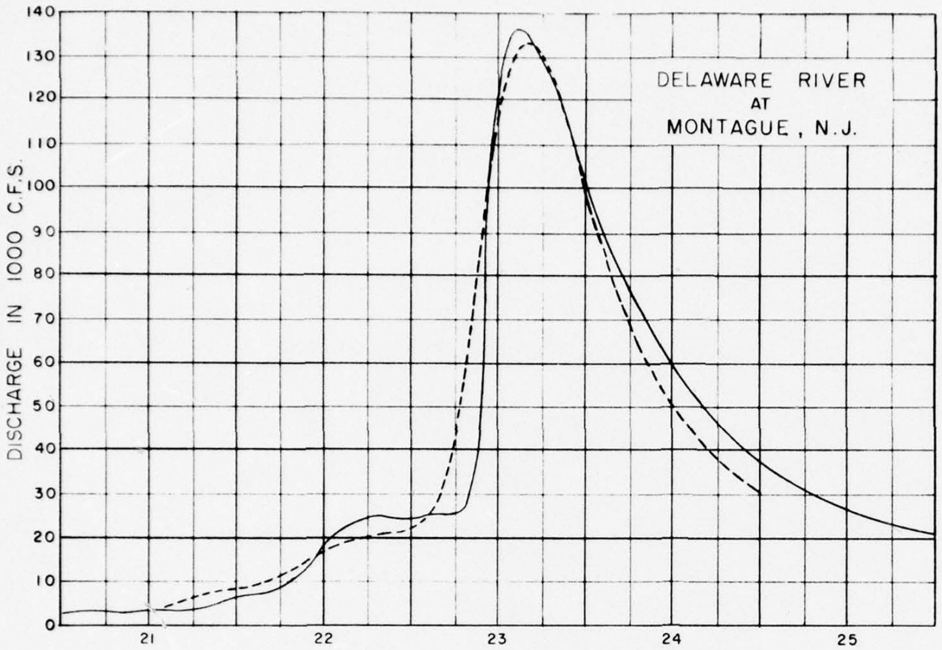
70
80
90
100
110
120
130
140
21

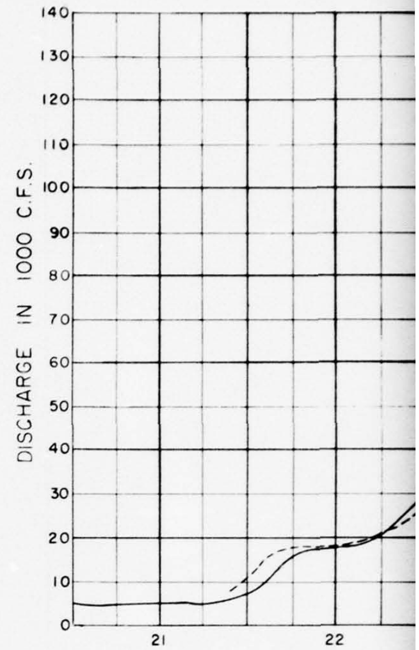
F L


DELAWARE RIVER
AT
PORT JERVIS, N.Y.
DISCHARGE IN 1000 C.F.S.
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
18
19
20
21
22

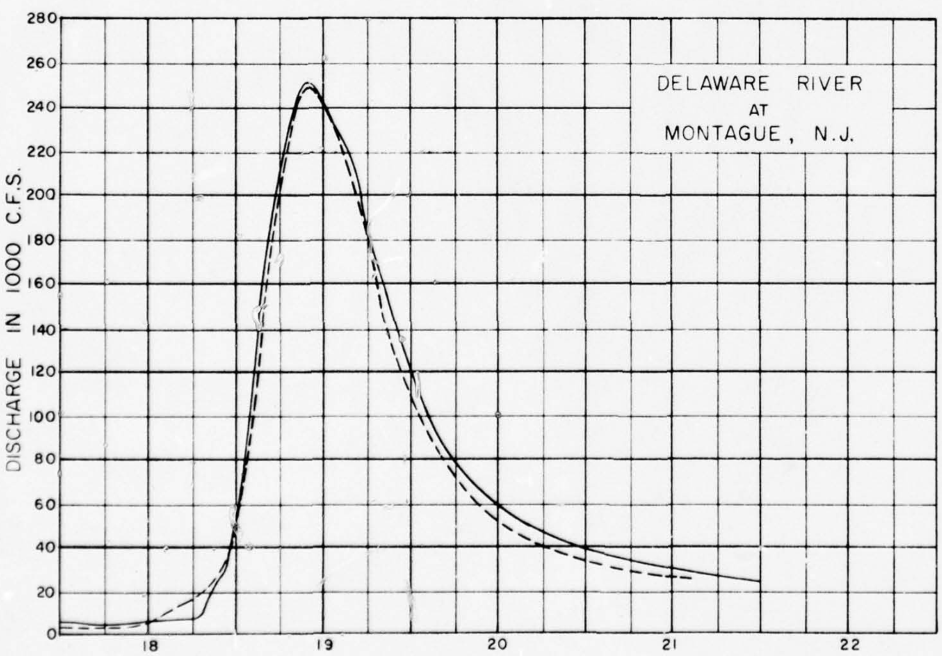

DISCHARGE IN 1000 C.F.S.
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
18

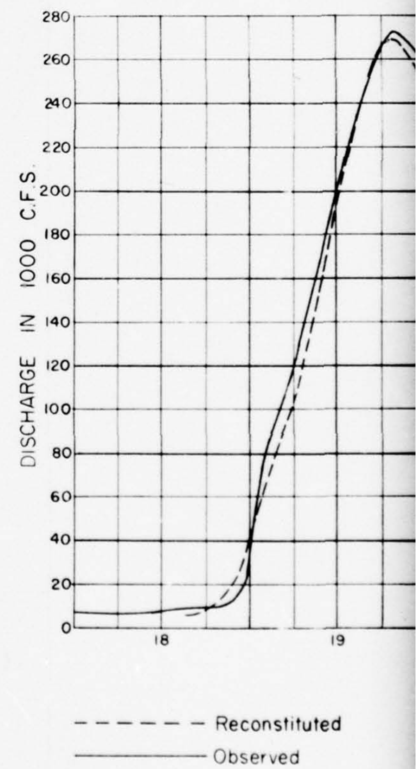
FLOOD OF MAY 1942





FLOOD OF AUGUST 1955





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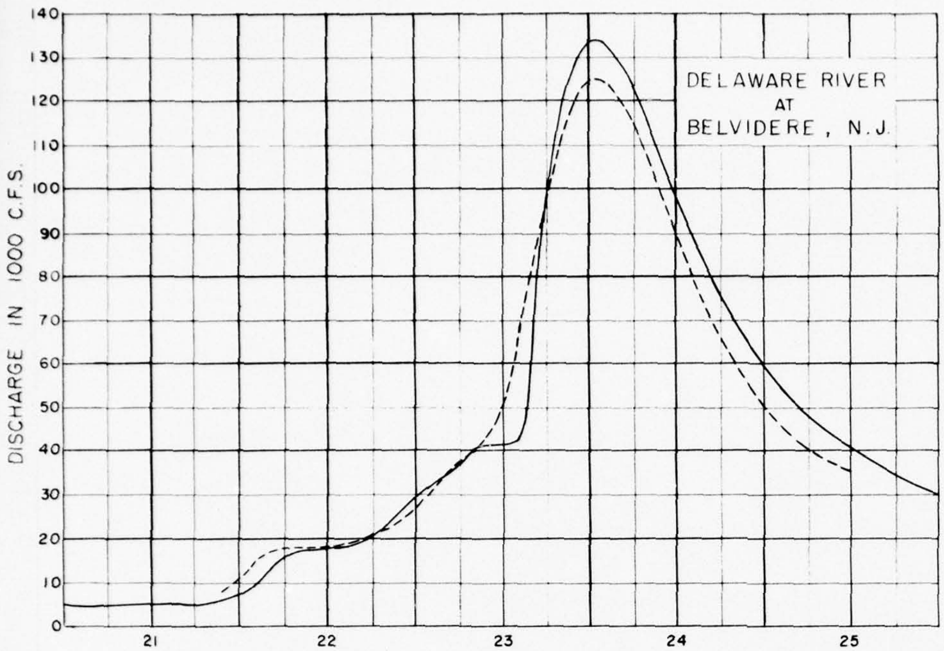
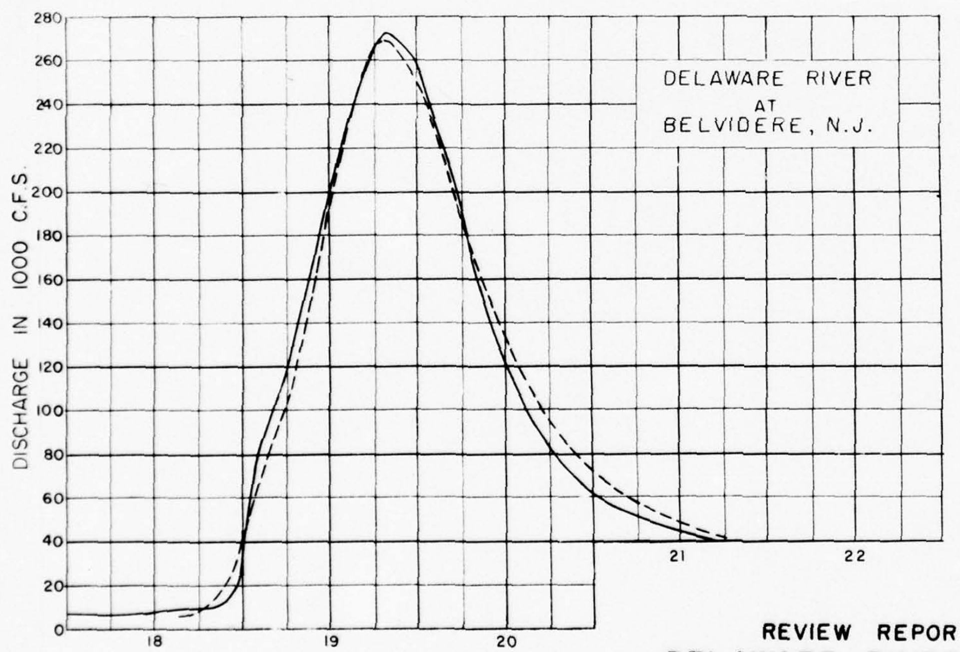




- - - - - - Reconstituted
——————— Observed

REVIEW REPORT

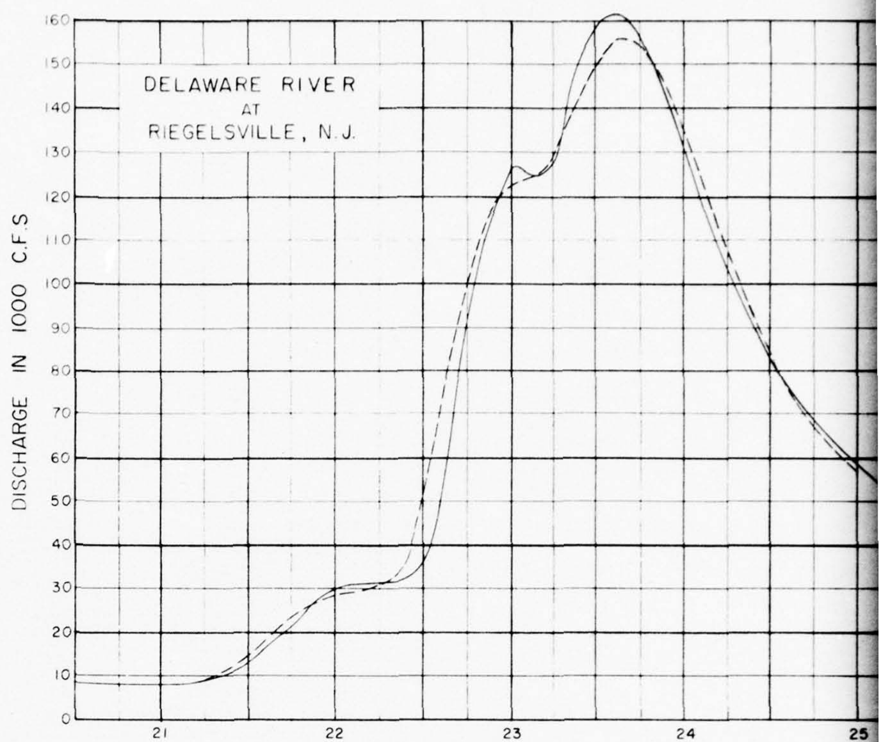
DELAWARE RIVER BASIN

OBSERVED & RECONSTITUTED HYDROGRAPHS
FOR DELAWARE RIVER STATIONS

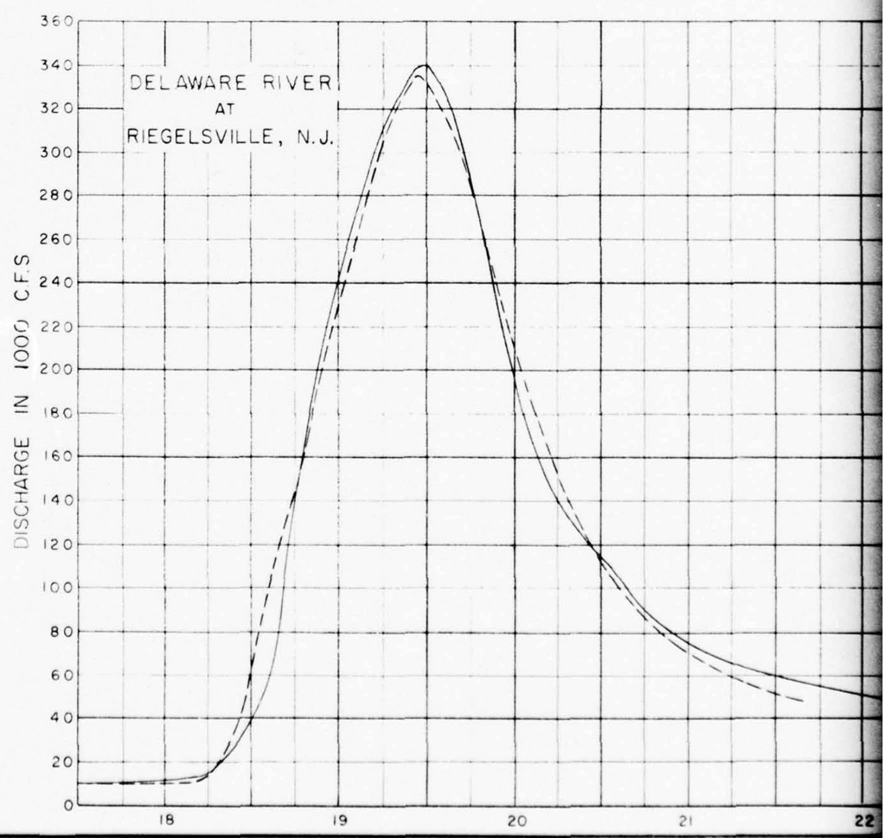
In 2 Sheets Sheet 1 Scales as Shown
Corps of Engineers Philadelphia District
Philadelphia, Pa. 30 Dec. 1959

Drawer No. 228 File No. 29031

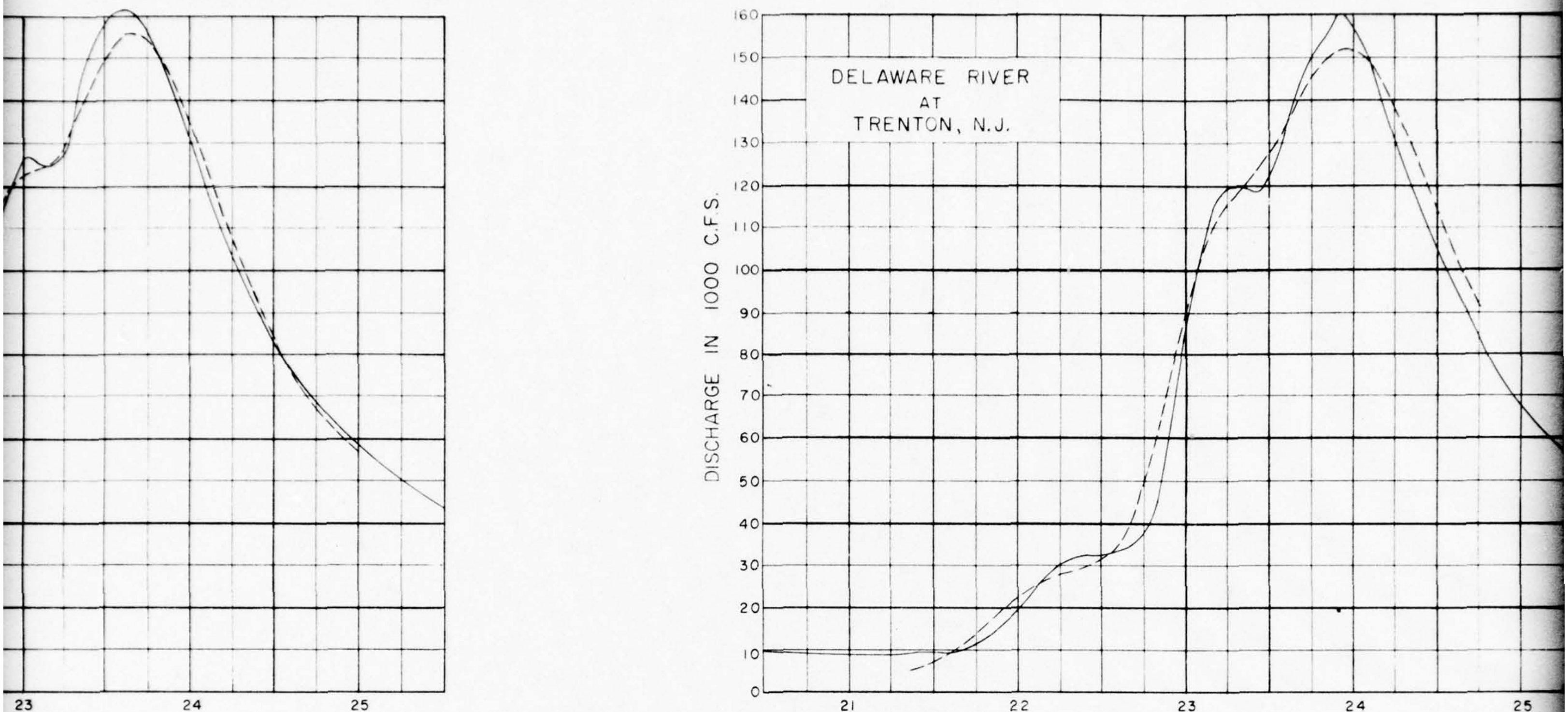
CORPS OF ENGINEERS



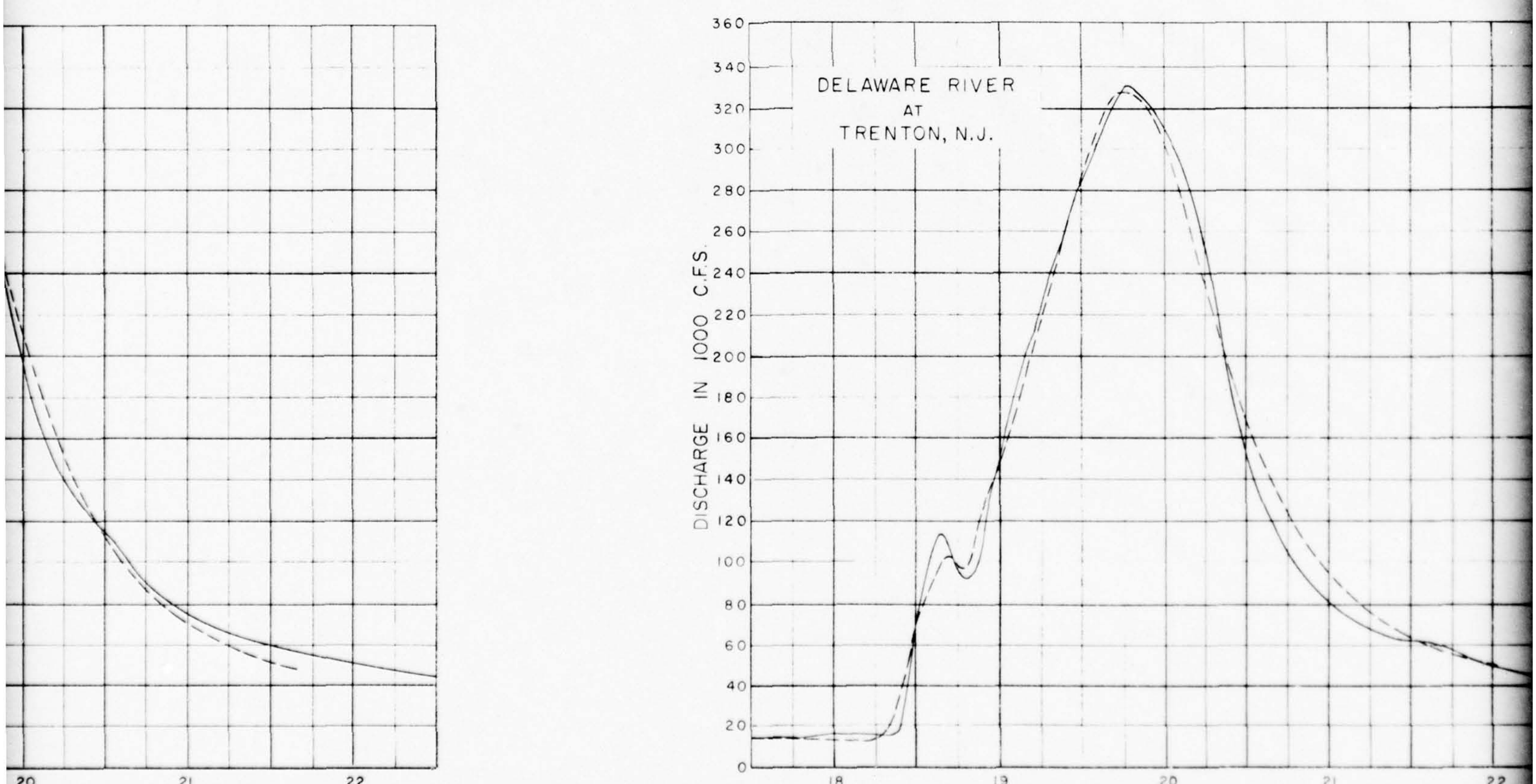
FLO



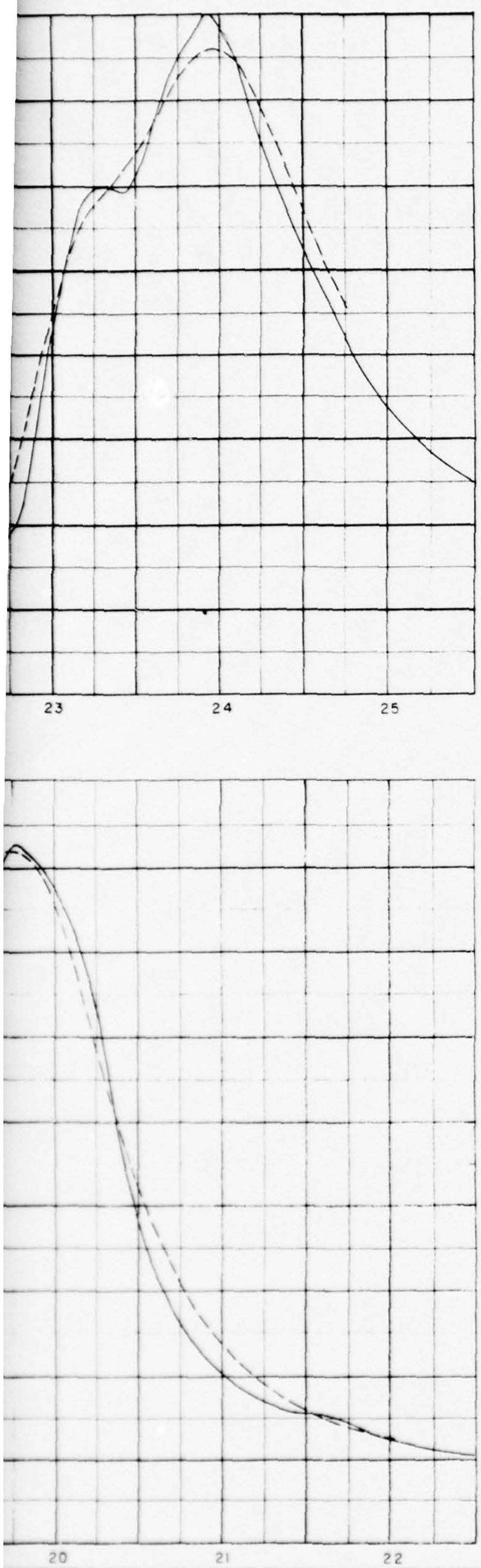
FLOOD OF MAY 1942



FLOOD OF AUGUST 1955



U. S. ARMY



REVIEW REPORT

DELAWARE RIVER BASIN

OBSERVED & RECONSTITUTED HYDROGRAPHS

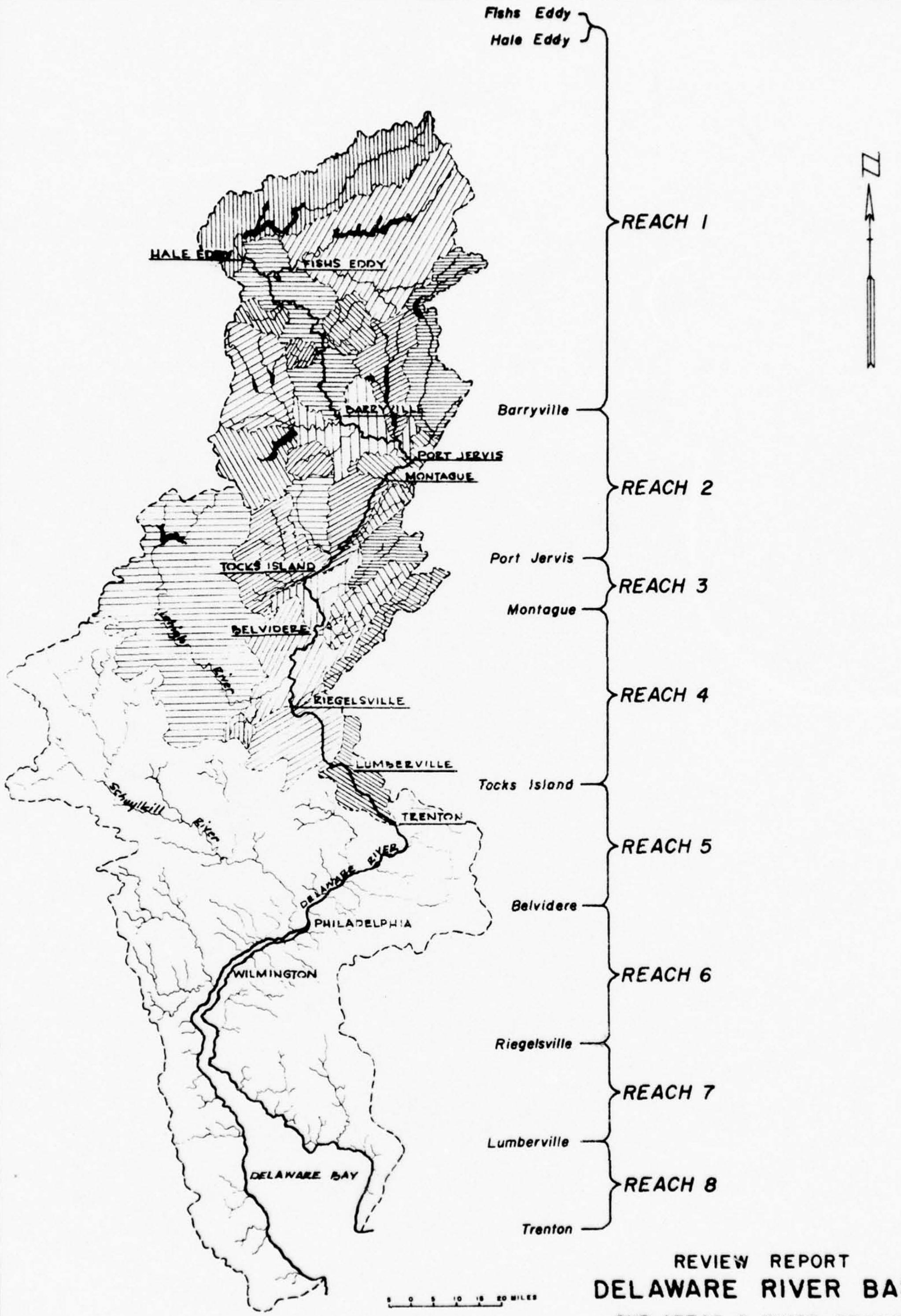
FOR DELAWARE RIVER STATIONS

In 2 Sheets — Sheet 2 — Scales as Shown
Corps of Engineers — Philadelphia District
Philadelphia, Pa — Dec 58

Drawer No 316 — File No. 29032

PLATE NO. 57

CORPS OF ENGINEERS U.S. ARMY



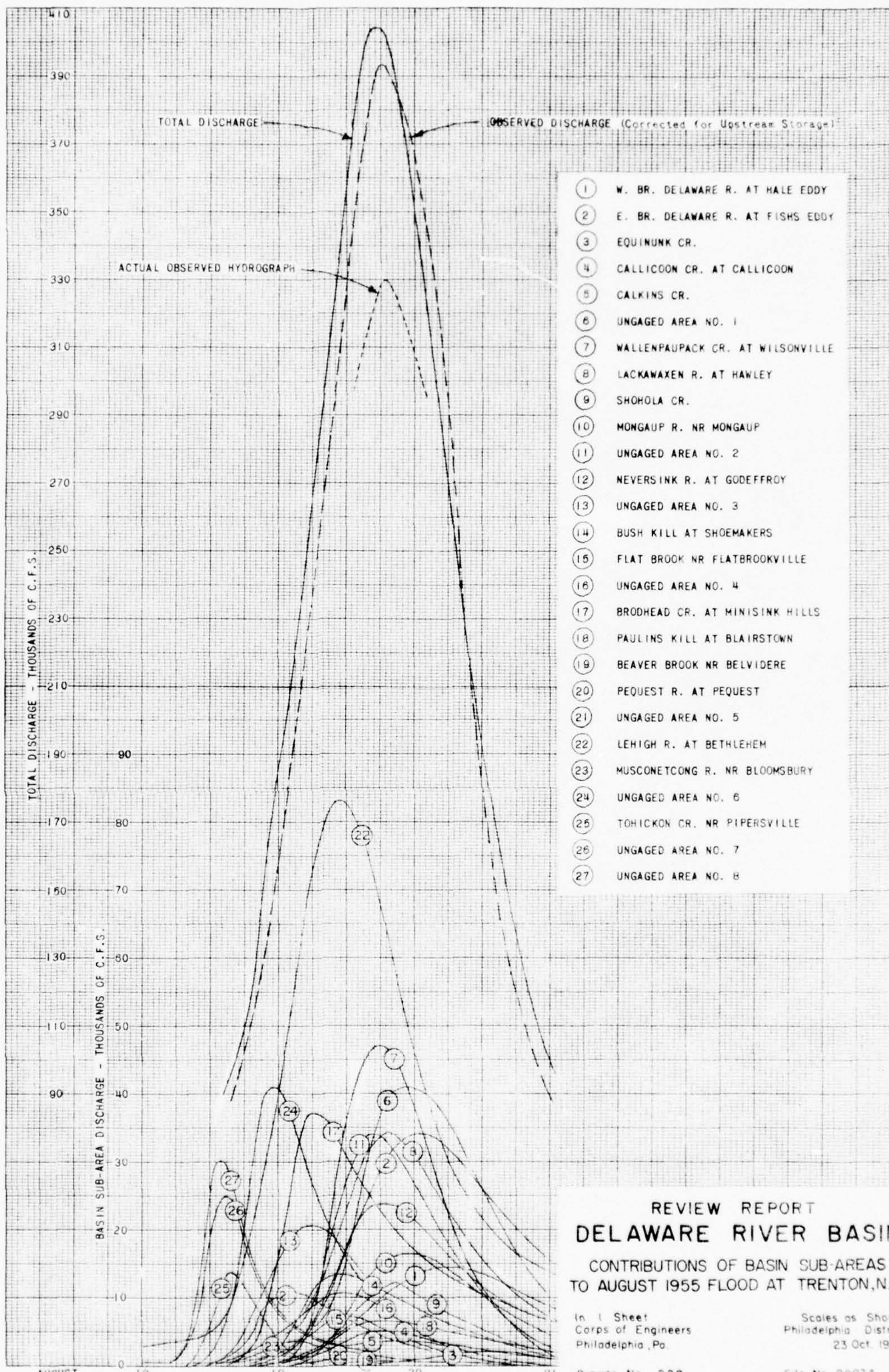
REVIEW REPORT

DELAWARE RIVER BASIN

SUB-AREAS & RIVER REACHES USED IN FLOOD ROUTING

In 1 Sheet	Scale as Shown
Corps of Engineers	Philadelphia District
Philadelphia, Pa.	November 1958
Drawer No. 228	File No. 29033

PLATE NO. 58



REVIEW REPORT

DELAWARE RIVER BASIN

CONTRIBUTIONS OF BASIN SUB-AREAS
TO AUGUST 1955 FLOOD AT TRENTON, N.J.

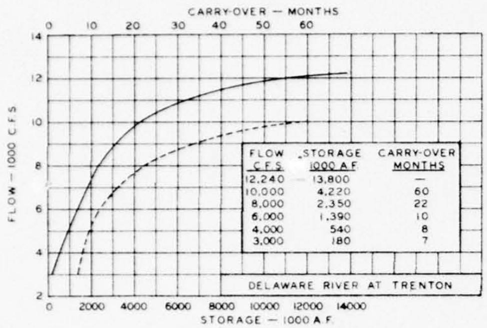
In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scales as Shown
Philadelphia District
23 Oct. 1959

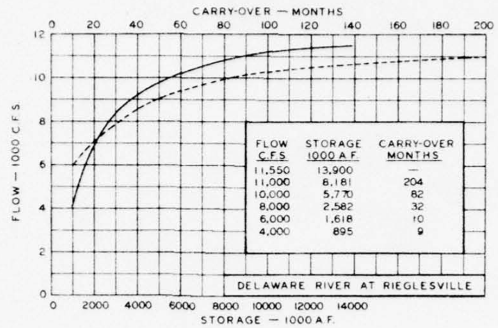
Drawer No. 228 File No. 29034

CORPS OF ENGINEERS

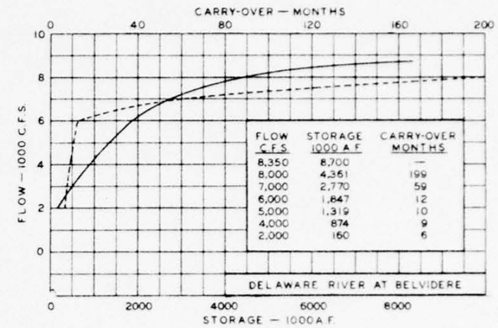
U.S. ARMY



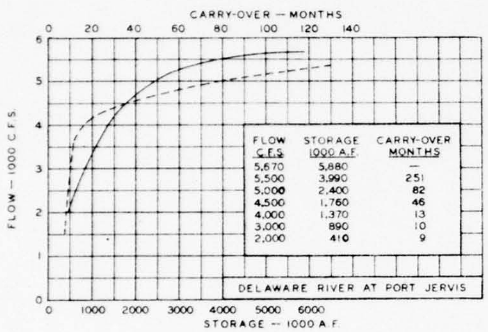
FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
12,240	13,800	—
10,000	4,220	60
8,000	2,350	22
6,000	1,390	10
4,000	540	8
3,000	180	7



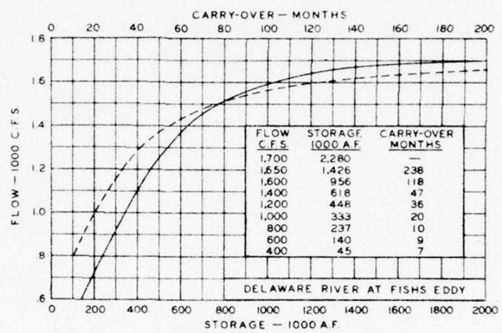
FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
11,550	13,900	—
11,000	8,181	204
10,000	5,770	82
8,000	2,582	32
6,000	1,618	10
4,000	895	9



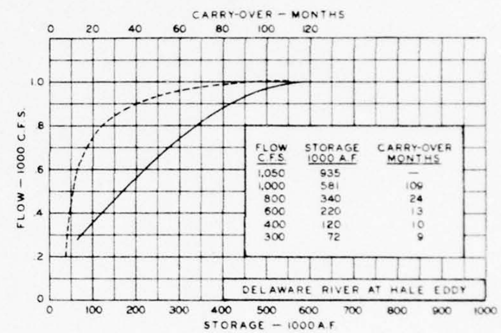
FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
8,350	8,700	—
8,000	4,361	199
7,000	2,770	59
6,000	1,847	12
5,000	1,319	10
4,000	874	9
2,000	160	6



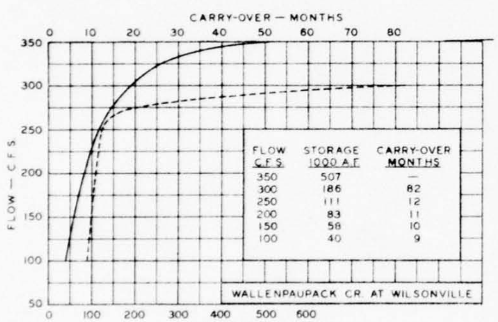
FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
5,670	5,880	—
5,500	3,990	251
5,000	2,400	82
4,500	1,760	46
4,000	1,370	13
3,000	890	10
2,000	410	9



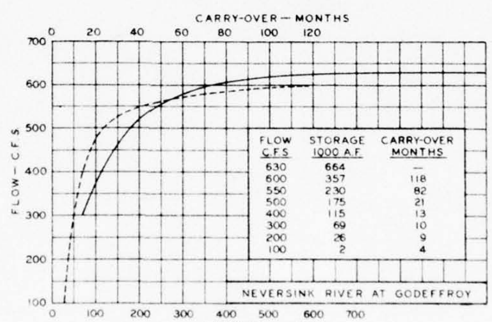
FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
1,700	2,280	—
1,650	1,426	238
1,600	956	118
1,400	618	47
1,200	448	36
1,000	333	20
800	237	10
600	140	9
400	45	7



FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
1,050	935	—
1,000	581	109
800	340	24
600	220	13
400	120	10
300	72	9



FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
350	507	—
300	186	82
250	111	12
200	83	11
150	58	10
100	40	9



FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
630	664	—
600	357	118
550	230	82
500	175	21
400	115	13
300	69	10
200	26	9
100	2	4

LEGEND

——— Flow versus storage

– – – Flow versus carry-over

REVIEW REPORT

DELAWARE RIVER BASIN

FLOW-STORAGE CURVES

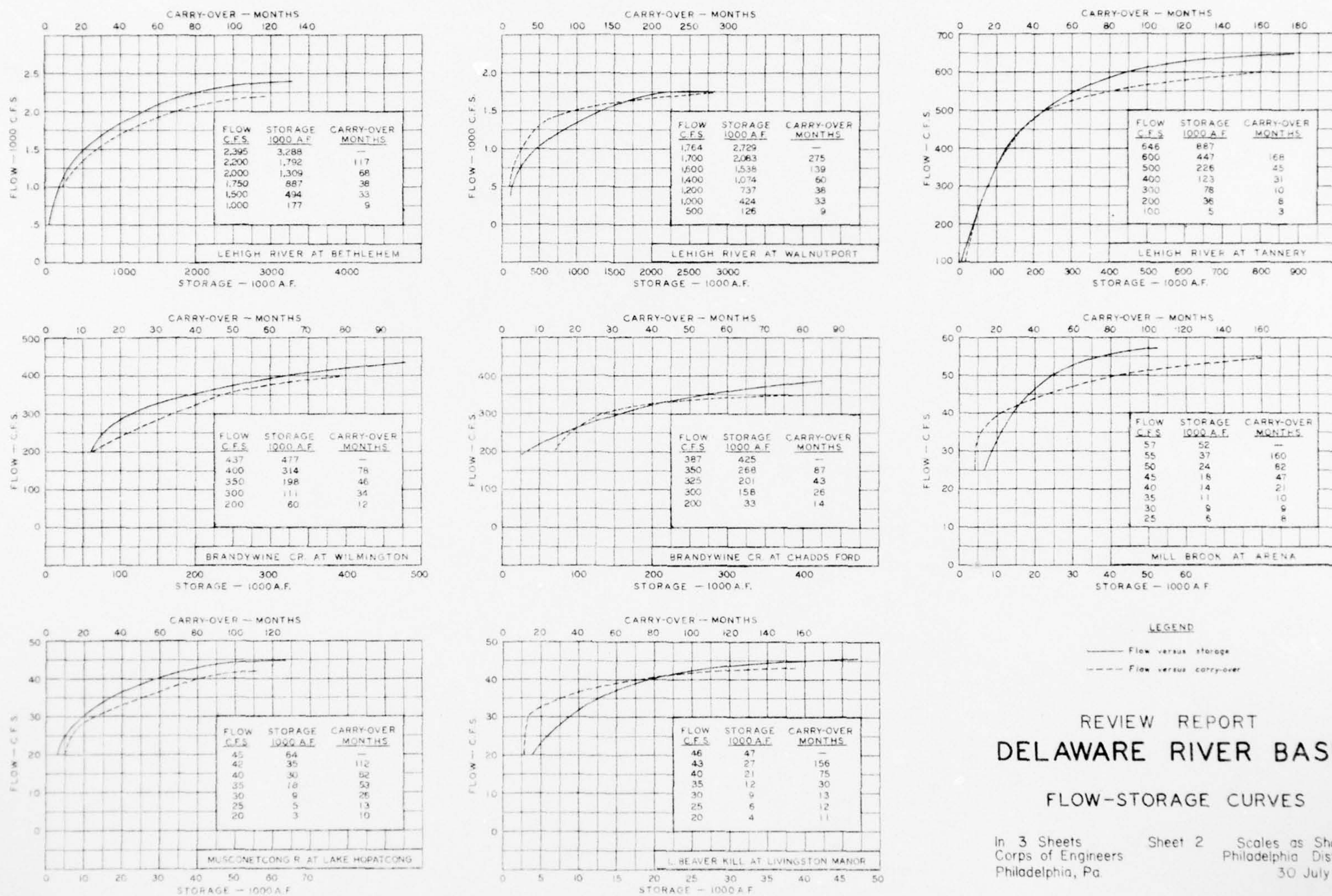
In 3 Sheets — Sheet 1 — Scales as Shown

Corps of Engineers, Philadelphia, Pa. — Philadelphia District, 14 July 58

Drawer No. 316 — File No. 29035

CORPS OF ENGINEERS

U. S. ARMY



LEHIGH RIVER AT BETHLEHEM

FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
2,395	3,288	—
2,200	1,792	117
2,000	1,309	68
1,750	887	38
1,500	494	33
1,000	177	9

LEHIGH RIVER AT WALNUTPORT

FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
1,764	2,729	—
1,700	2,083	275
1,600	1,538	139
1,400	1,074	60
1,200	737	38
1,000	424	33
500	126	9

LEHIGH RIVER AT TANNERY

FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
646	887	—
600	447	168
500	226	45
400	123	31
300	78	10
200	36	8
100	5	3

BRANDYWINE CR. AT WILMINGTON

FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
437	477	—
400	314	78
350	198	46
300	111	34
200	60	12

BRANDYWINE CR. AT CHADDS FORD

FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
387	425	—
350	268	87
325	201	43
300	158	26
200	33	14

MILL BROOK AT ARENA

FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
57	52	—
55	37	160
50	24	62
45	18	47
40	14	21
35	11	10
30	9	9
25	6	8

MUSCONETCONG R. AT LAKE HOPATCONG

FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
45	64	—
42	35	112
40	30	82
35	18	53
30	9	28
25	5	13
20	3	10

L. BEAVER KILL AT LIVINGSTON MANOR

FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
46	47	—
43	27	156
40	21	75
35	12	30
30	9	13
25	6	12
20	4	11

REVIEW REPORT

DELAWARE RIVER BASIN

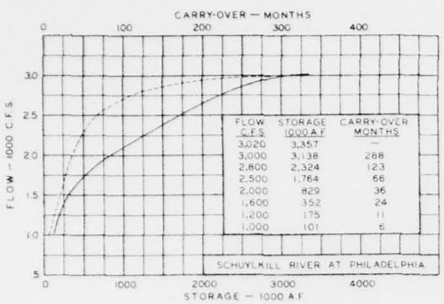
FLOW-STORAGE CURVES

In 3 Sheets   Sheet 2   Scales as Shown
Corps of Engineers   Philadelphia District
Philadelphia, Pa.   30 July 58

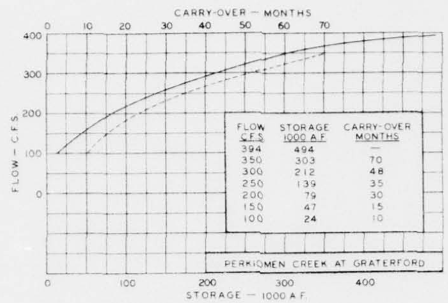
Drawer No. 316   File No. 29036

CORPS OF ENGINEERS

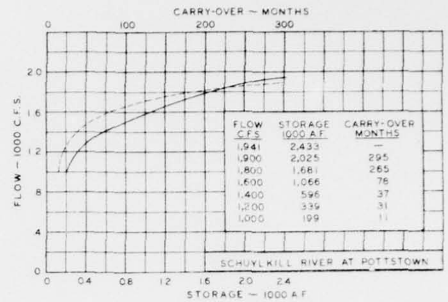
U.S. ARMY



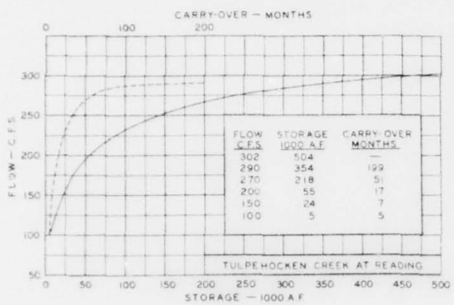
FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
3,020	3,357	—
3,000	3,138	288
2,800	2,324	123
2,500	1,764	66
2,000	829	36
1,600	352	24
1,200	175	11
1,000	101	6



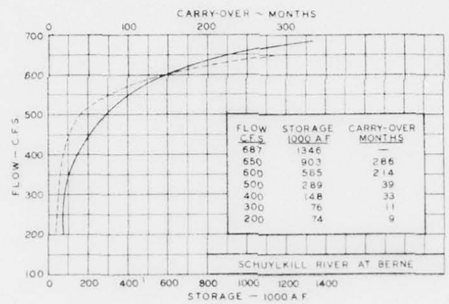
FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
394	494	—
350	303	70
300	212	48
250	139	35
200	79	30
150	47	15
100	24	10



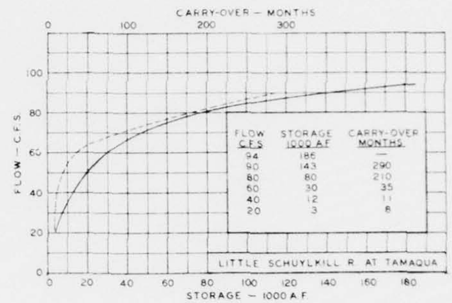
FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
1,941	2,433	—
1,900	2,025	295
1,800	1,681	265
1,600	1,066	78
1,400	596	37
1,200	339	31
1,000	199	11



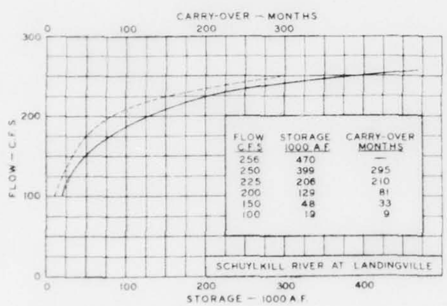
FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
302	504	—
290	354	199
270	218	51
200	55	17
150	24	7
100	5	5



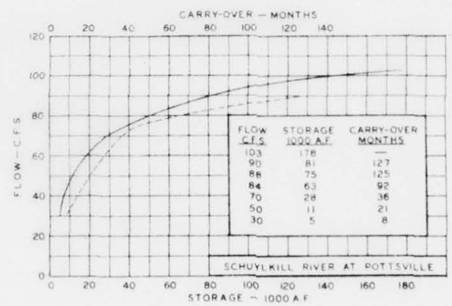
FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
687	1346	—
650	903	286
600	565	214
500	289	39
400	148	33
300	76	11
200	74	9



FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
94	186	—
90	143	290
80	80	210
60	30	35
40	12	11
20	3	8



FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
256	470	—
250	399	295
225	206	210
200	129	81
150	48	33
100	19	9



FLOW C.F.S.	STORAGE 1000 A.F.	CARRY-OVER MONTHS
103	178	—
90	81	127
88	75	125
84	63	92
70	28	36
50	11	21
30	5	8

LEGEND

——— Flow versus storage

- - - - Flow versus carry-over

REVIEW REPORT

DELAWARE RIVER BASIN

FLOW-STORAGE CURVES

In 3 Sheets Sheet 3 Scales as Shown
Corps of Engineers Philadelphia District
Philadelphia, Pa. 30 June 58

Drawer No. 316 File No. 29037

CORPS OF ENGINEERS U.S. ARMY

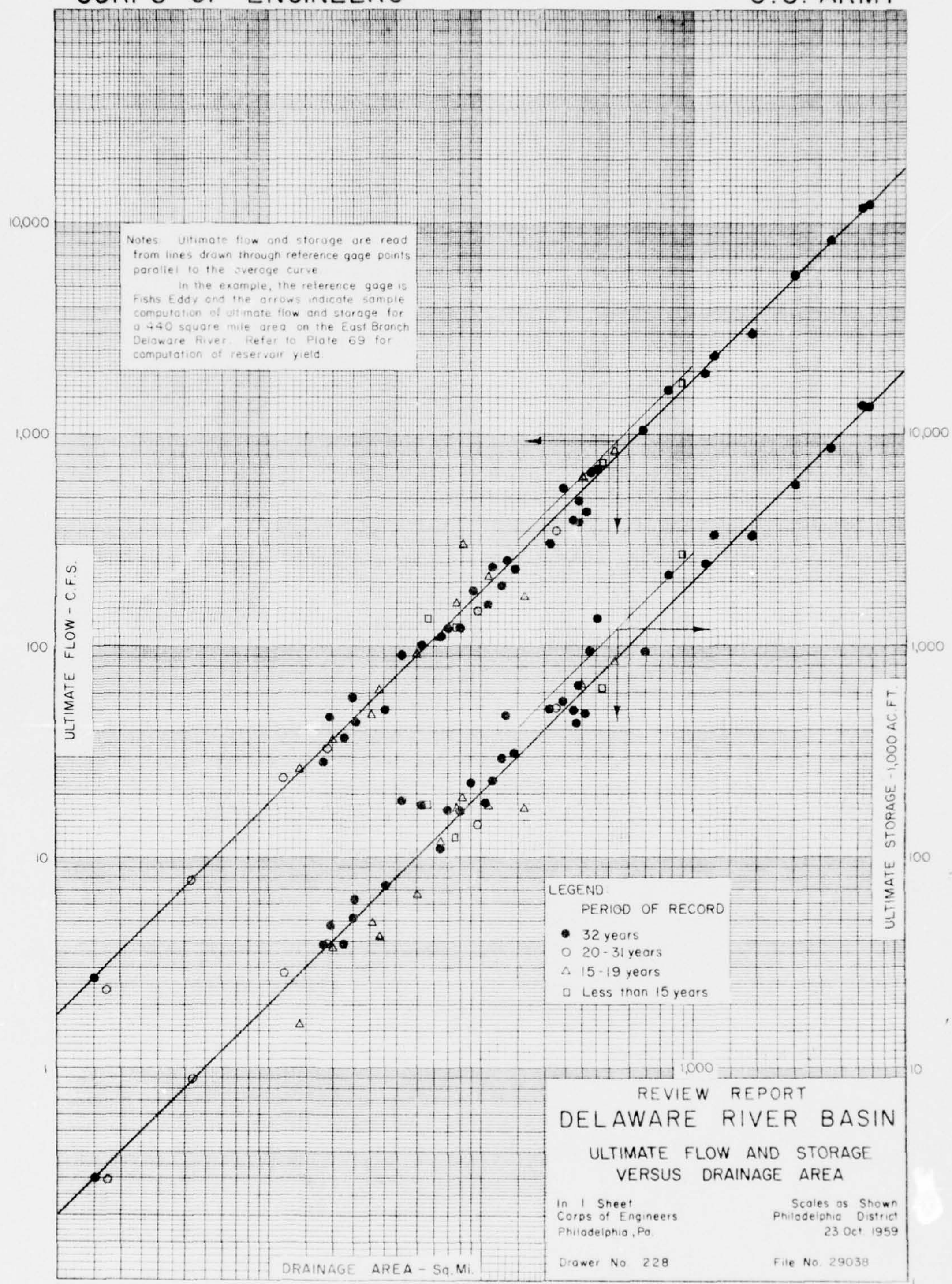
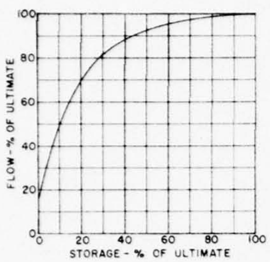


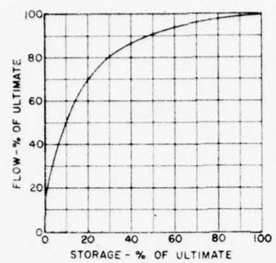
PLATE NO. 63

CORPS OF ENGINEERS

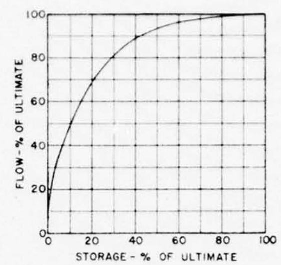
U.S. ARMY



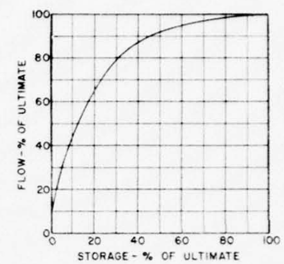
DELAWARE R. AT TRENTON



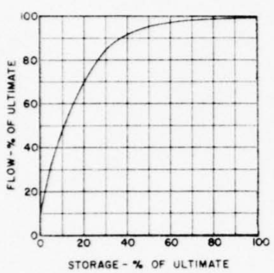
DELAWARE R. AT RIEGELSVILLE



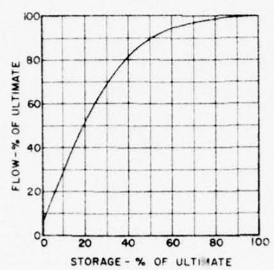
DELAWARE R. AT BELVIDERE



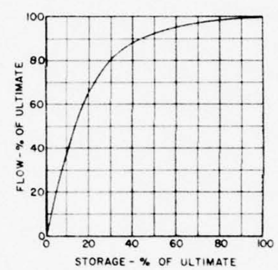
DELAWARE R. AT PORT JERVIS



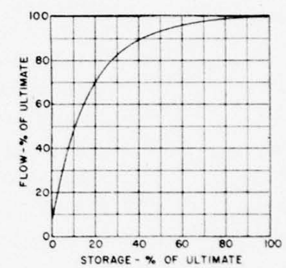
EAST B. AT FISHS EDDY



WEST BR. AT HALE EDDY



WALLENPAUPACK CR. AT WILSONVILLE



NEVERSINK R. AT GODEFFROY

REVIEW REPORT

DELAWARE RIVER BASIN

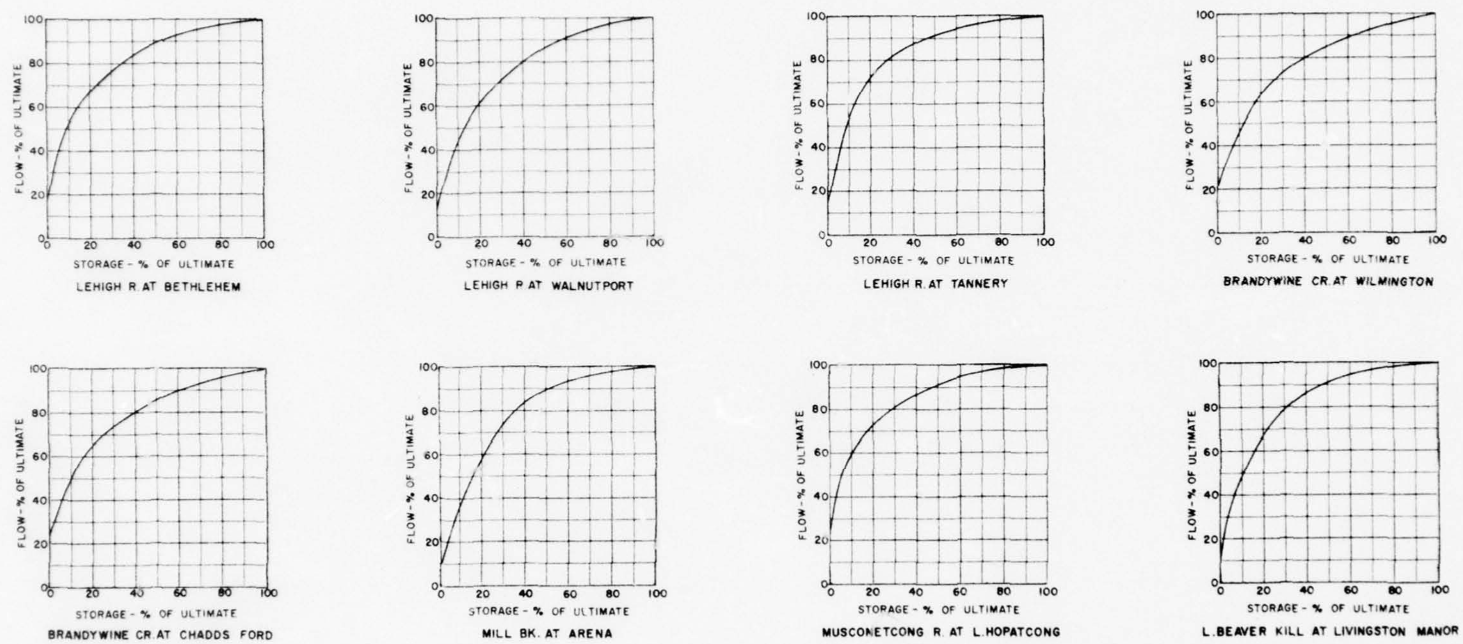
DIMENSIONLESS FLOW - STORAGE CURVES

In 3 Sheets — Sheet 1 — Scales as Shown
Corps of Engineers — Philadelphia District
Philadelphia, Pa. — January 1959

Drawer No. 316 — File No. 29039

CORPS OF ENGINEERS

U.S. ARMY



REVIEW REPORT

DELAWARE RIVER BASIN

DIMENSIONLESS FLOW-STORAGE CURVES

In 3 Sheets
Corps of Engineers
Philadelphia, Pa.

Sheet 2

Scales as Shown
Philadelphia District
January 1959

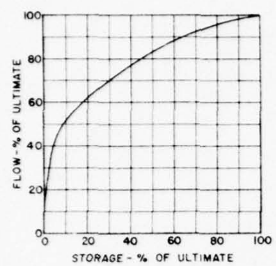
Drawer No. 316

File No. 29040

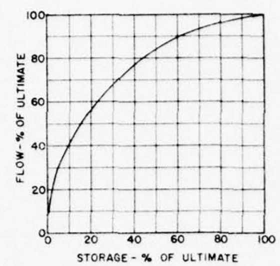
PLATE NO. 65

CORPS OF ENGINEERS

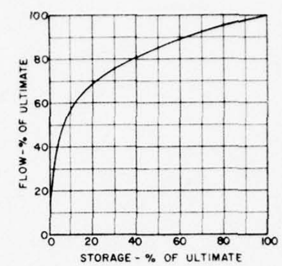
U.S. ARMY



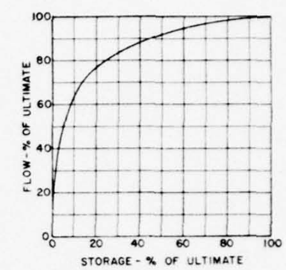
SCHUYLKILL R. AT PHILADELPHIA



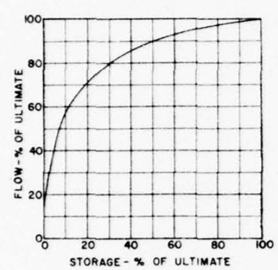
PERKIOMEN CR. AT GRATERFORD



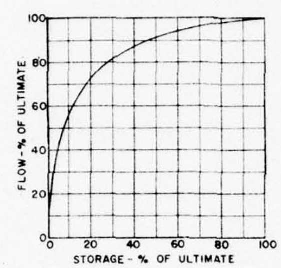
SCHUYLKILL R. AT POTTSTOWN



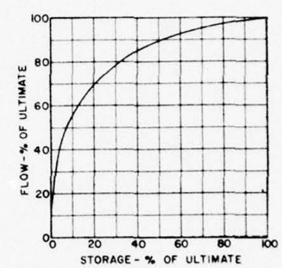
TULPEHOCKEN CR. AT READING



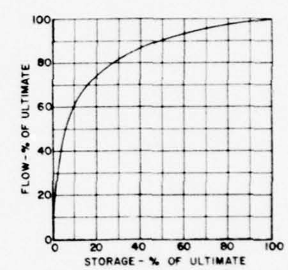
SCHUYLKILL R. AT BERNE



L. SCHUYLKILL R. AT TAMAQUA



SCHUYLKILL R. AT LANDINGVILLE



SCHUYLKILL R. AT POTTSVILLE

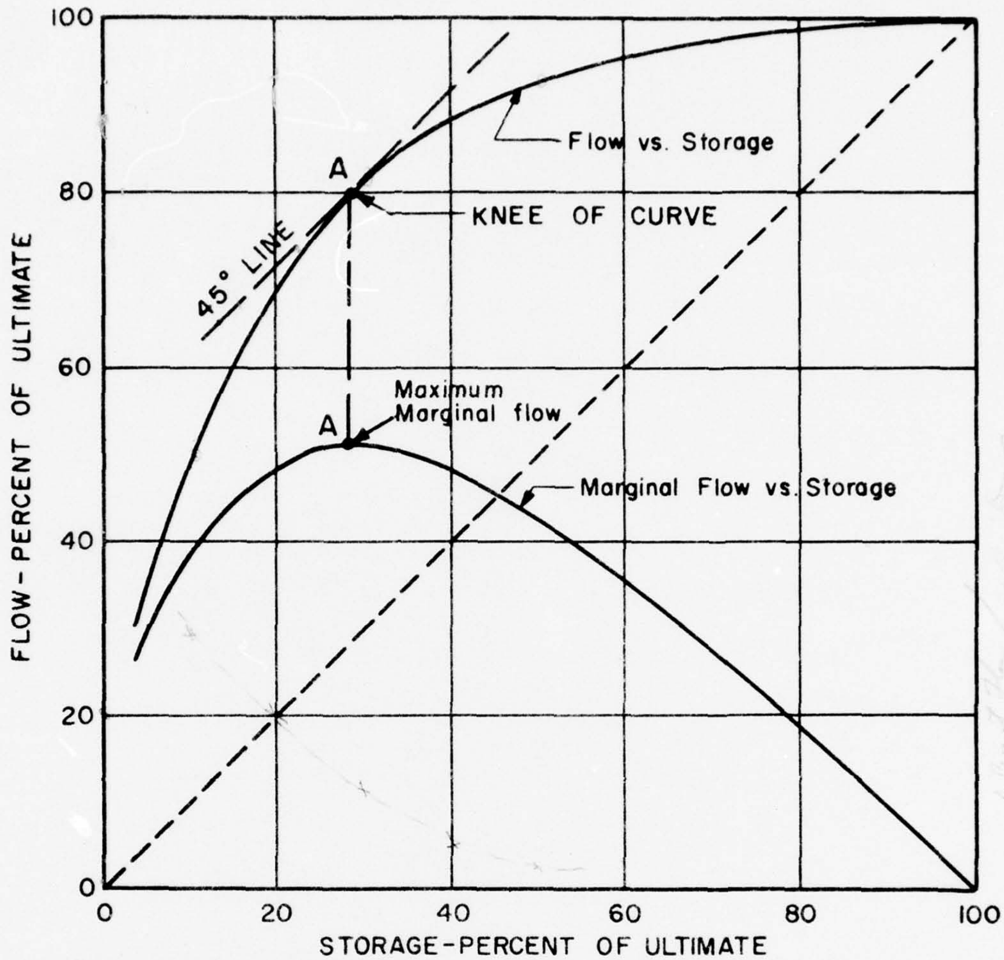
REVIEW REPORT

DELAWARE RIVER BASIN

DIMENSIONLESS FLOW-STORAGE CURVES

In 3 Sheets **Sheet 3** **Scales as Shown**
Corps of Engineers **Philadelphia District**
Philadelphia, Pa. **January 1959**

Drawer No. 316 **File No. 29041**

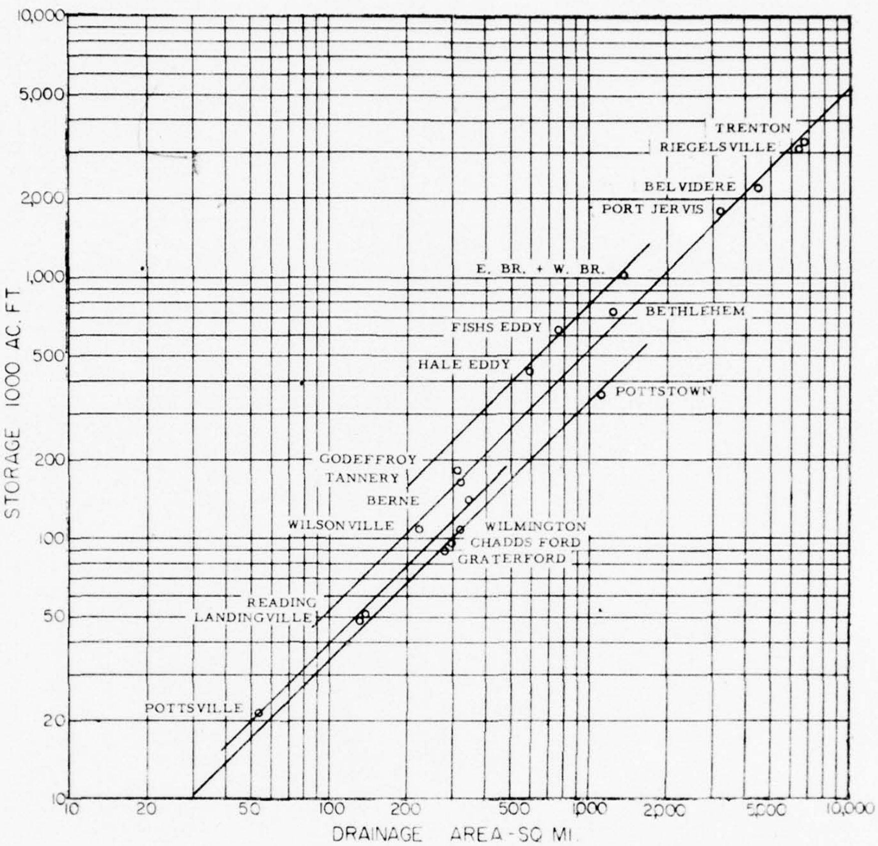


NOTE:

Optimum development is realized at Knee of curve, point A, where marginal flow is maximum. Point A is found by drawing 45° line tangent to flow storage curve. Optimum development here is at 24% of ultimate storage with a yield of 80% of ultimate flow.

REVIEW REPORT
DELAWARE RIVER BASIN
OPTIMUM DEVELOPMENT
FROM FLOW-STORAGE CURVE

In 1 Sheet — Scales as Shown
Corps of Engineers — Phila. Dist.
Drawer 228 File No. 29042 — January 59



REVIEW REPORT

DELAWARE RIVER BASIN

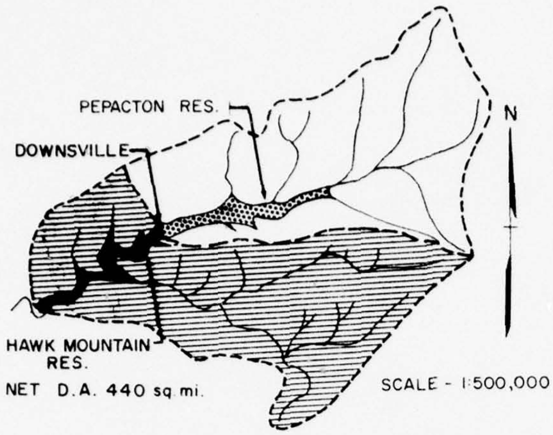
"KNEE" STORAGE VERSUS DRAINAGE AREA

In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scales as Shown
Philadelphia District
23 Oct. 1959

Drawer No. 228

File No. 29043



SAMPLE COMPUTATION

Find the yield of Hawk Mountain reservoir.

(1) Given:

Net drainage area	=	440 sq. mi.
Project storage	=	290,000 A.F.
Location:		E. Branch Del. R.

(2) Refer to Plate 63. & Text paragraph 122.

Ultimate flow	=	940 c.f.s.
Ultimate storage	=	1,200,000 A.F.

(3) Compute % storage $= \frac{\text{project storage}}{\text{ultimate storage}}$

$= \frac{290,000}{1,200,000}$

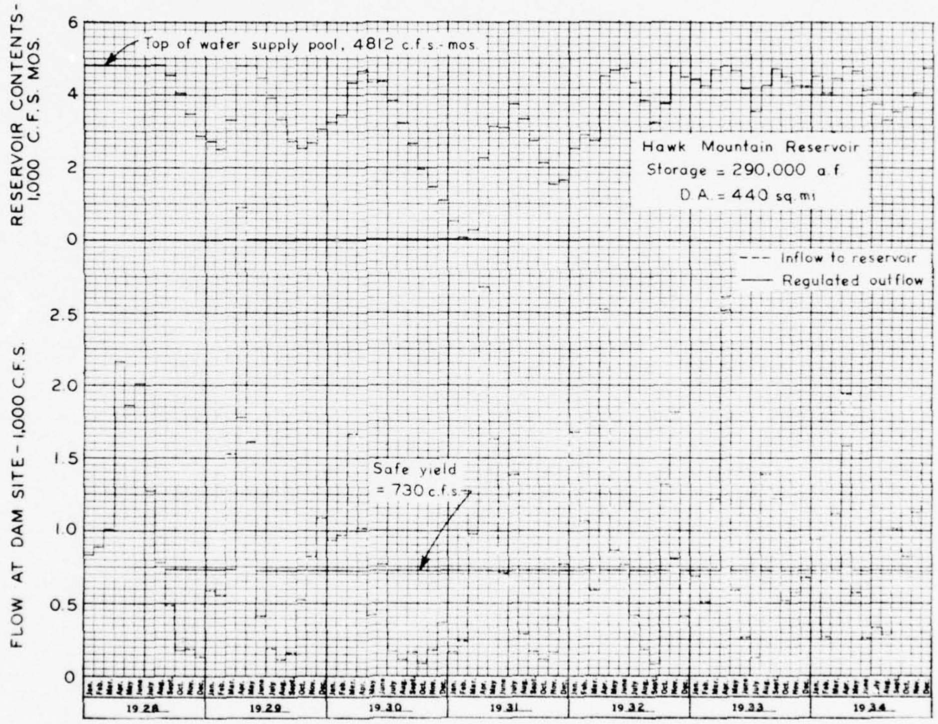
$=$ 24%

(4) Refer to Plate 64.

Dimensionless flow storage curve for E. Branch

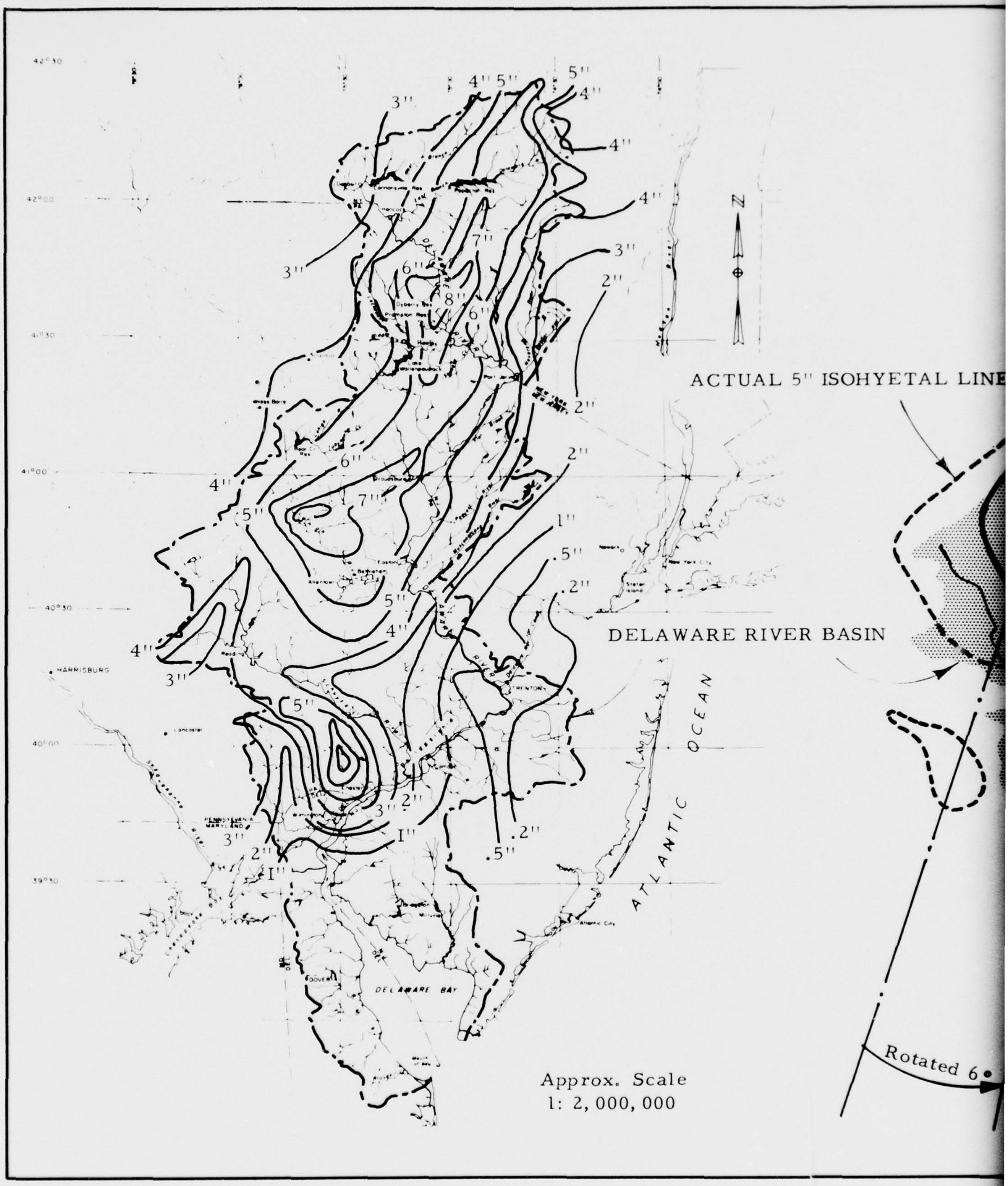
24% Storage gives 78% of ultimate flow

.78 x 940 = 730 c.f.s.

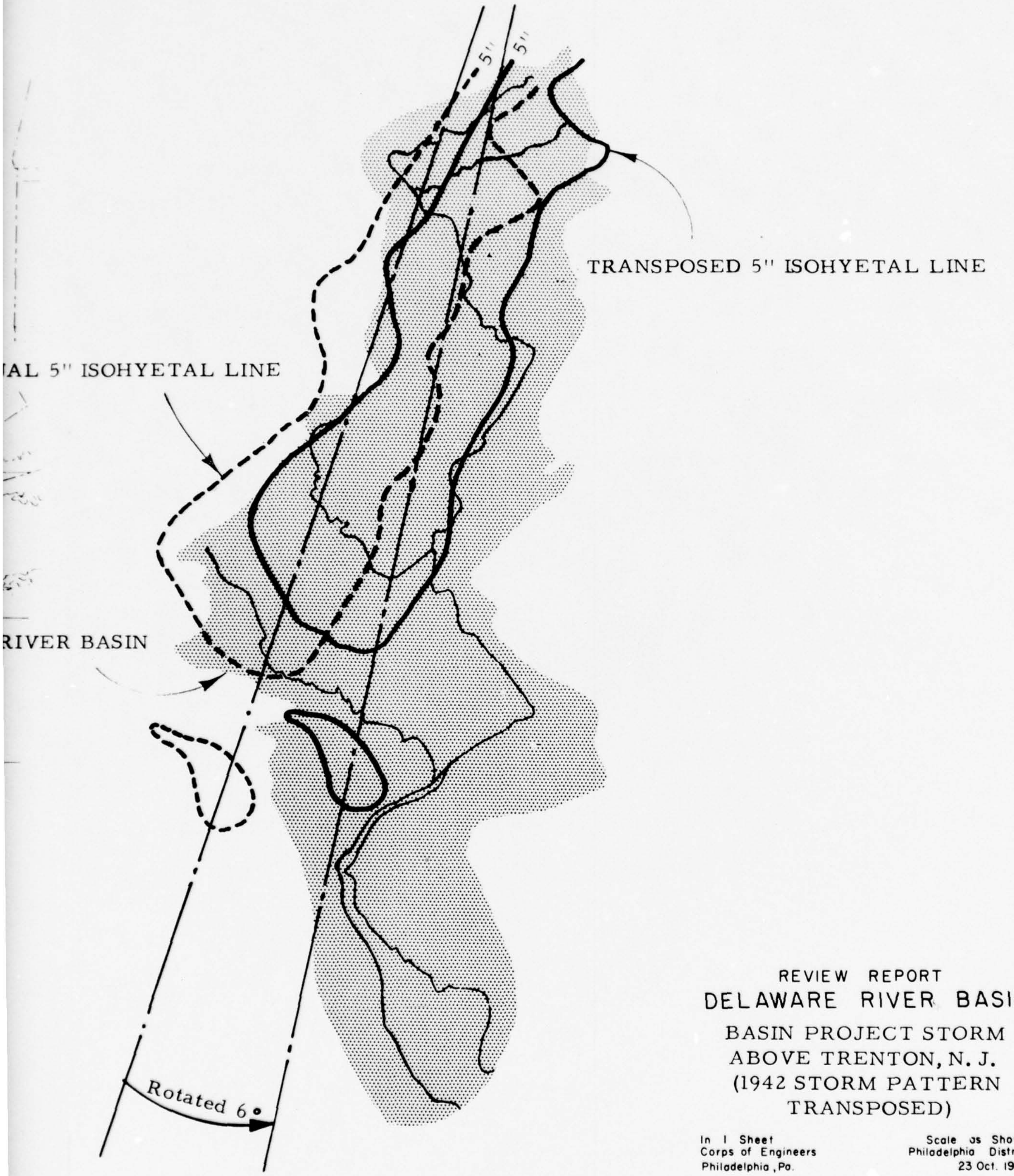


REVIEW REPORT
DELAWARE RIVER BASIN
OPERATION OF HAWK MTN. RESERVOIR FOR WATER SUPPLY

In 1 Sheet	Scales as Shown
Corps of Engineers	Philadelphia District
Philadelphia, Pa.	23 Oct. 1959
Drawer No. 228	File No. 29044



ACTUAL 5'' ISOHYETAL LINE
DELAWARE RIVER BASIN
ATLANTIC OCEAN
DELAWARE BAY
HARRISBURG
TRENTON
DOVER
Rotated 6°
Approx. Scale
1: 2,000,000



REVIEW REPORT
DELAWARE RIVER BASIN
BASIN PROJECT STORM
ABOVE TRENTON, N. J.
(1942 STORM PATTERN
TRANSPOSED)

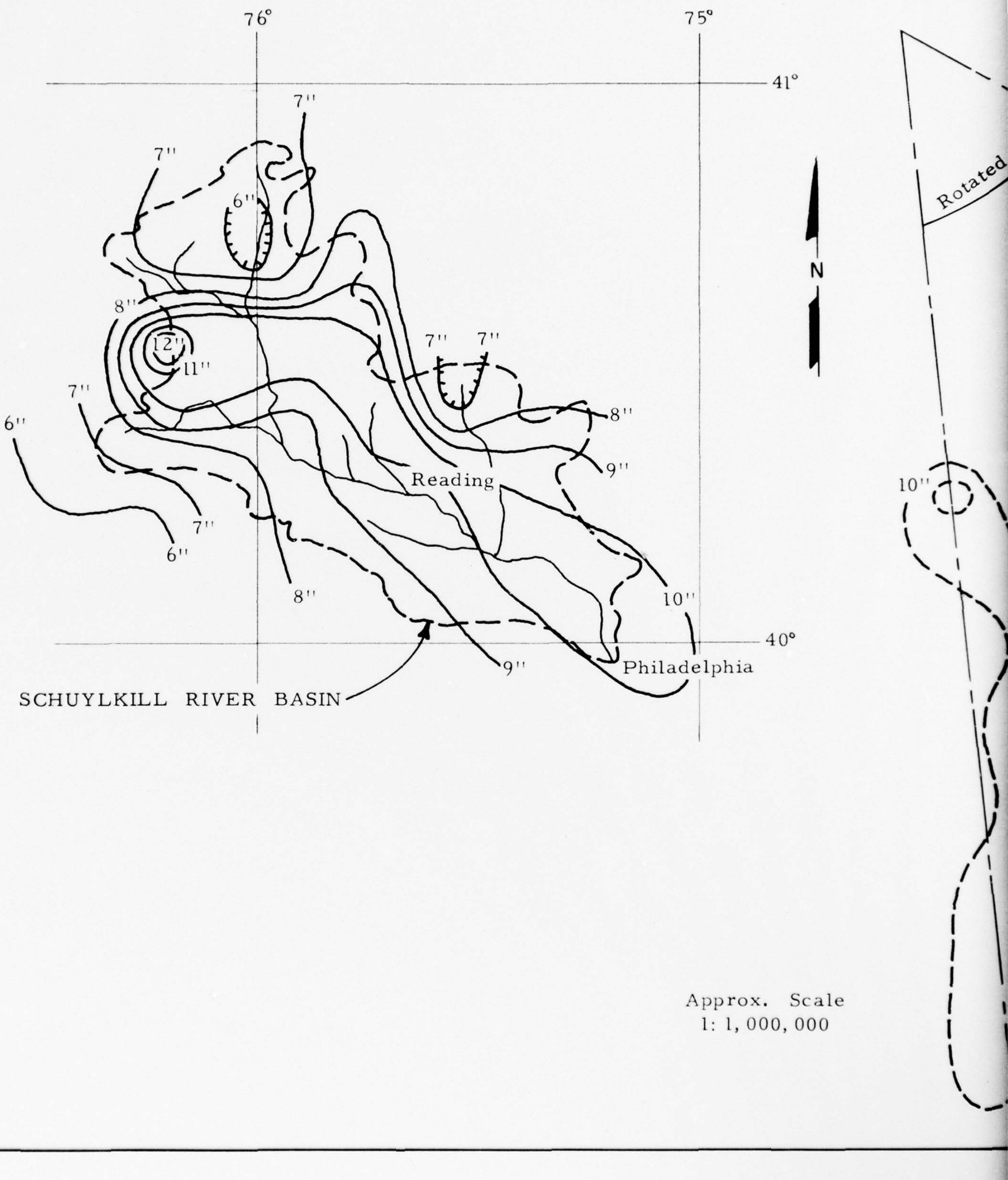
In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scale as Shown
Philadelphia District
23 Oct. 1959

Drawer No. 228

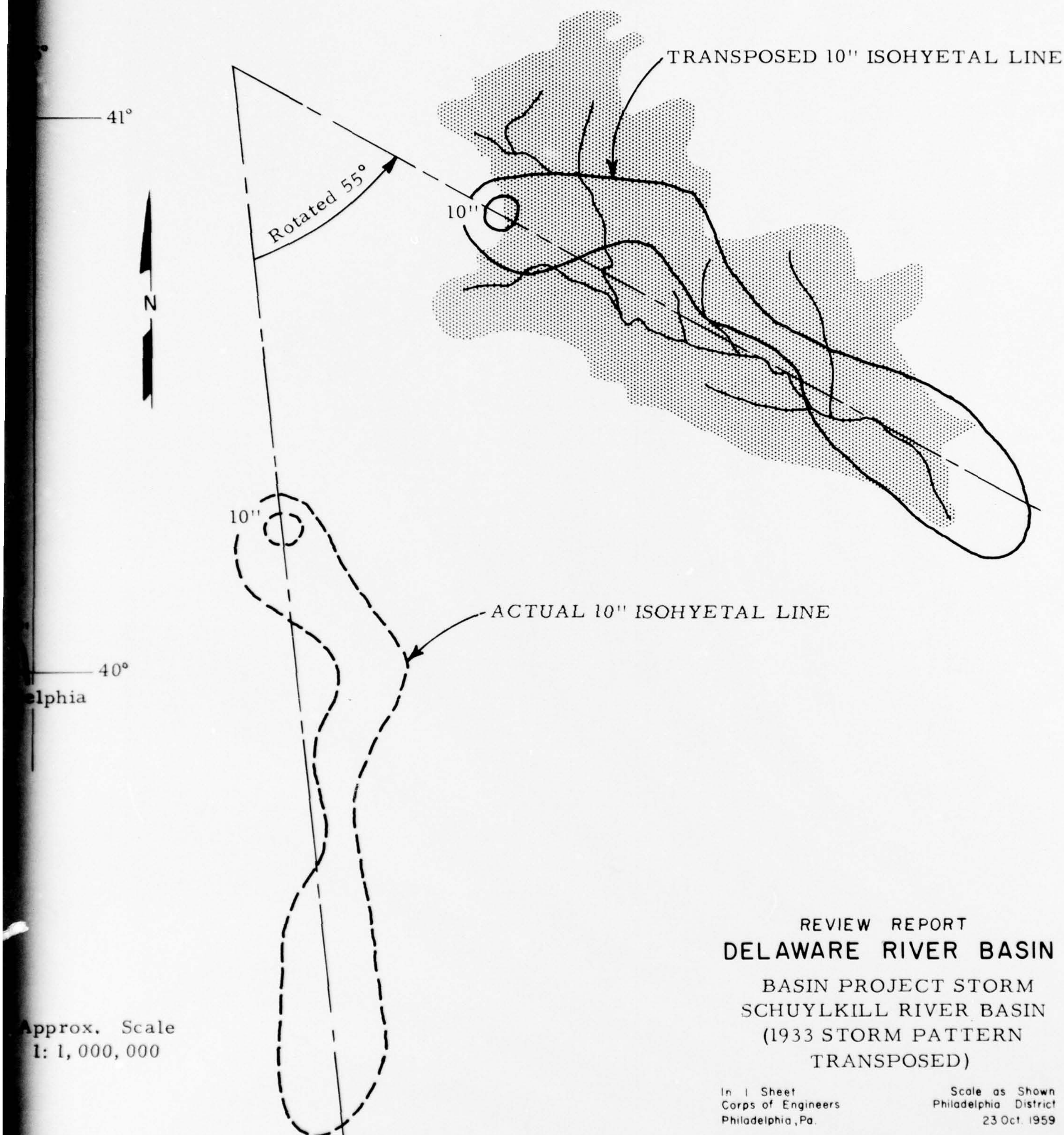
File No. 29045

CORPS OF ENGINEERS



Approx. Scale
1: 1,000,000

U.S. ARMY



REVIEW REPORT

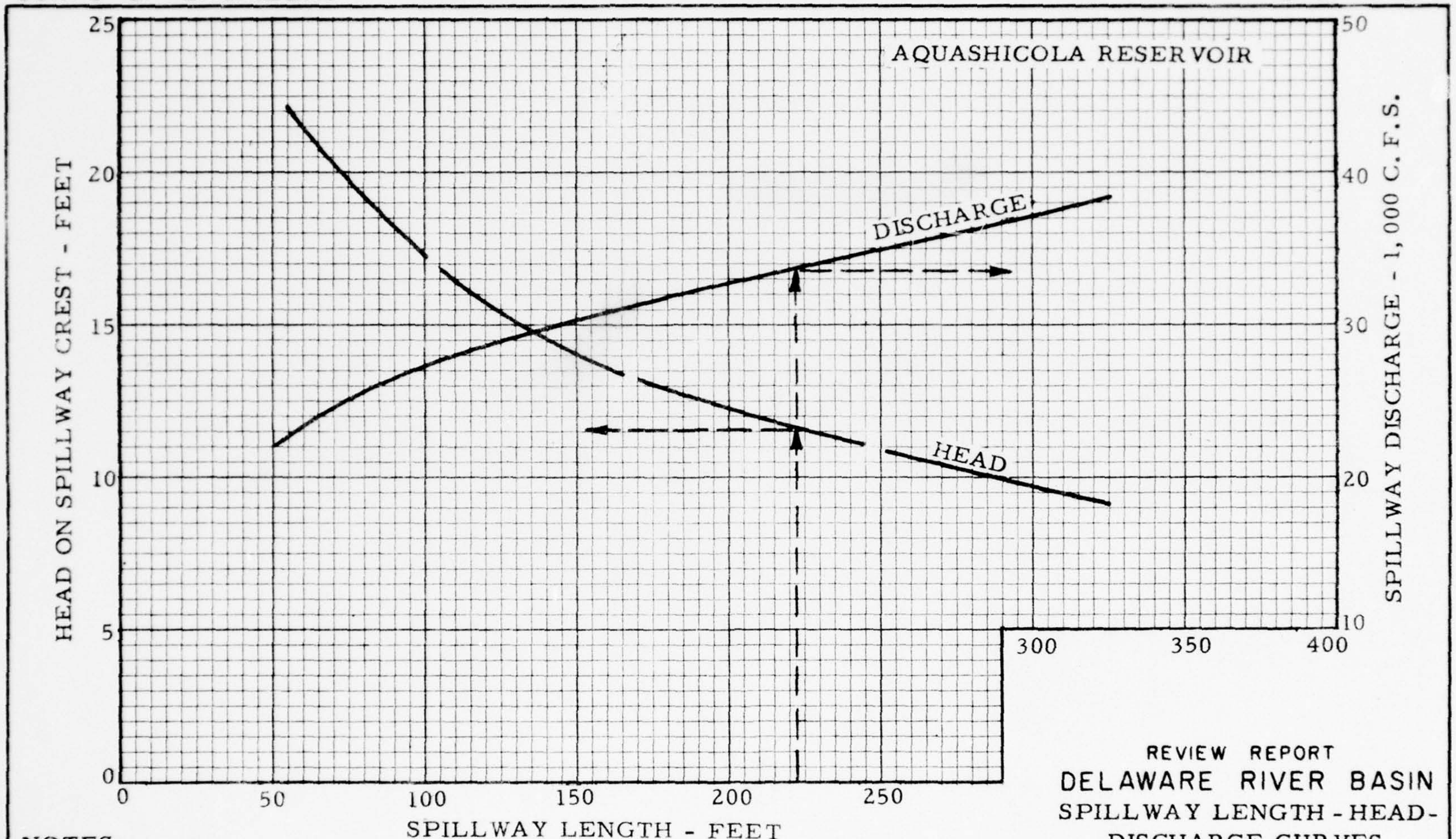
DELAWARE RIVER BASIN

BASIN PROJECT STORM
SCHUYLKILL RIVER BASIN
(1933 STORM PATTERN
TRANSPOSED)

In 1 Sheet	Scale as Shown
Corps of Engineers	Philadelphia District
Philadelphia, Pa.	23 Oct. 1959
Drawer No. 228	File No. 29047

PLATE NO. 71

CORPS OF ENGINEERS U. S. ARMY



NOTES:

1. Curves based on reservoir routings of spillway design flood with pool level at spillway crest at begining of inflow. Peak inflow = 43,000 C. F. S.
2. Spillway crest at elevation 503.0 ft. m. s. l.

REVIEW REPORT

DELAWARE RIVER BASIN

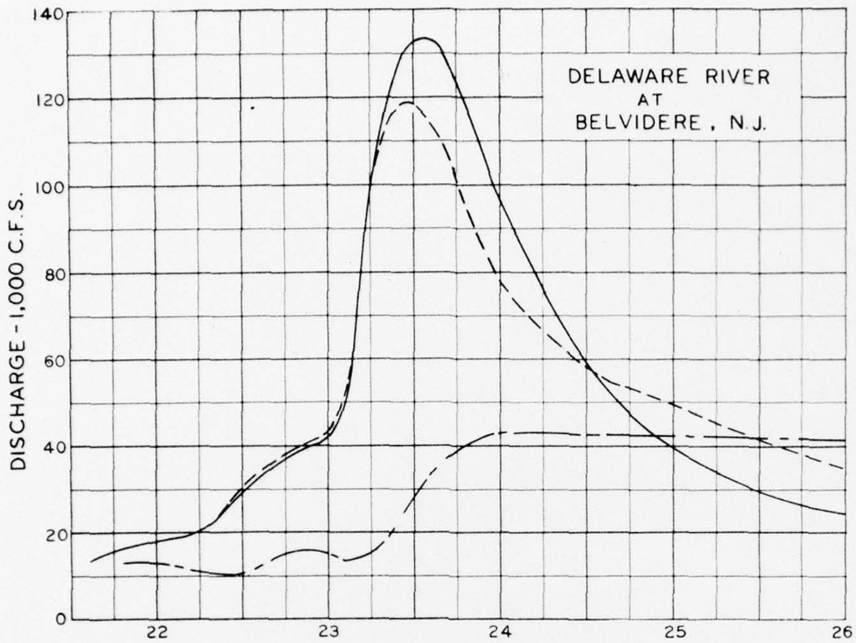
SPILLWAY LENGTH - HEAD-DISCHARGE CURVES

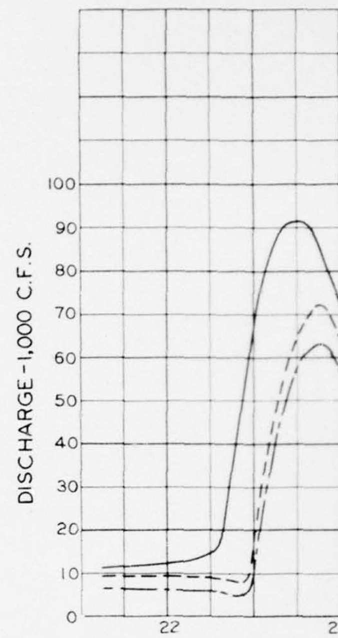
In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

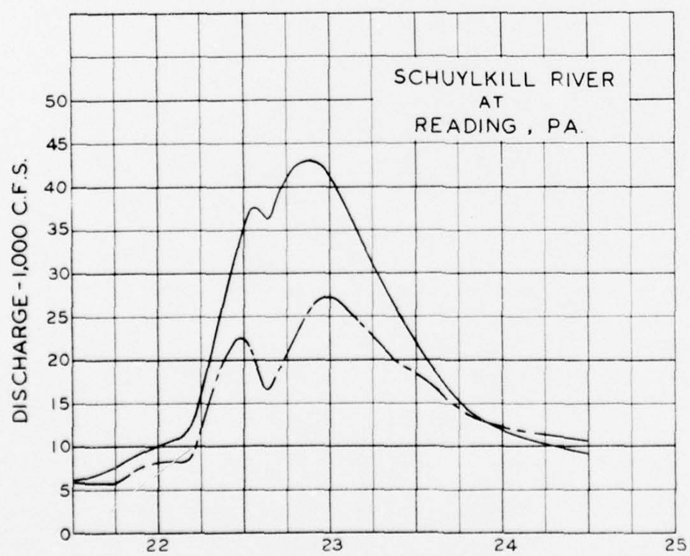
Scale as Shown
Philadelphia District
23 Oct. 1959

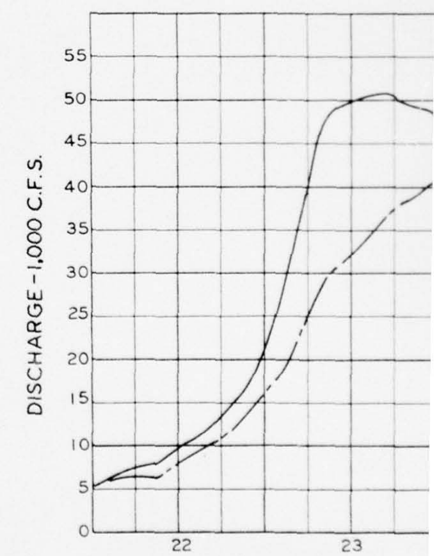
Drawer No. 228

File No. 29046

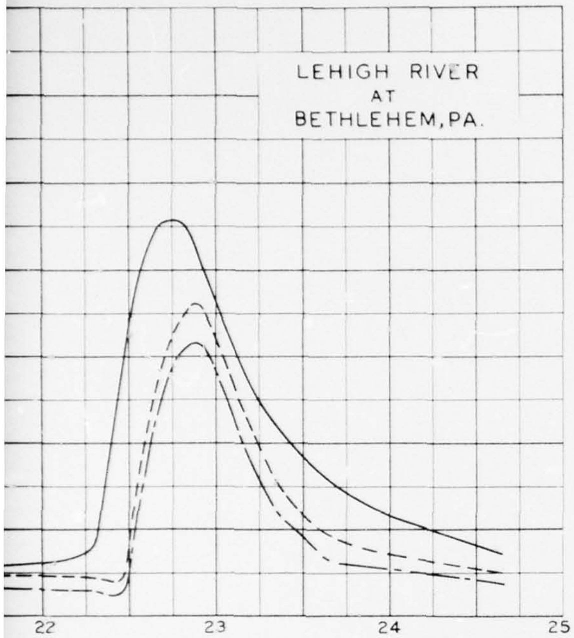

DELAWARE RIVER
AT
BELVIDERE, N.J.
DISCHARGE - 1,000 C.F.S.
0
20
40
60
80
100
120
140
22
23
24
25
26

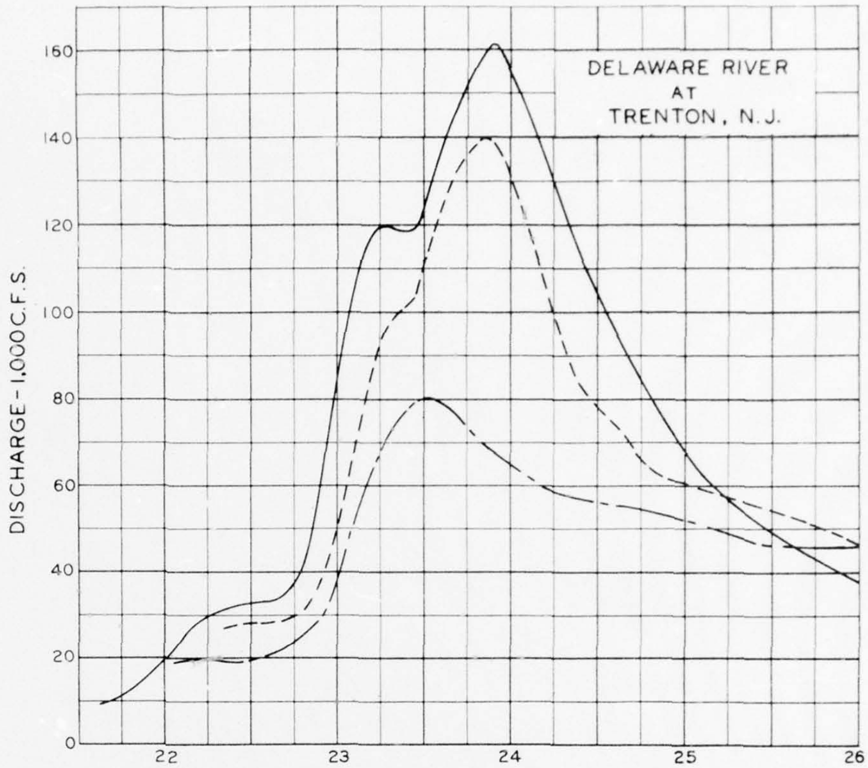

DISCHARGE - 1,000 C.F.S.
0
10
20
30
40
50
60
70
80
90
100
22

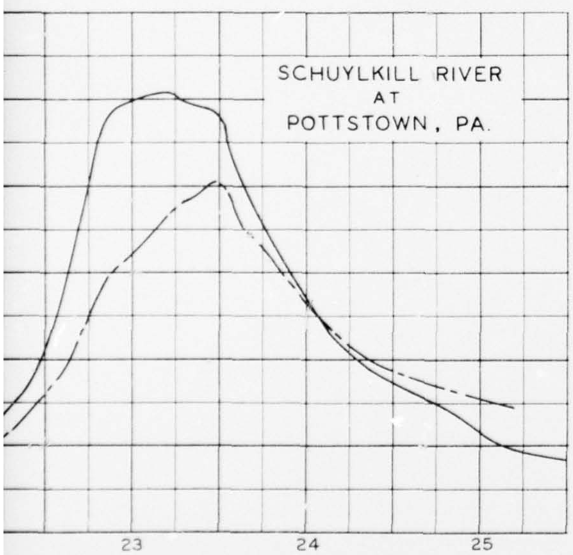

SCHUYLKILL RIVER
AT
READING, PA.
DISCHARGE - 1,000 C.F.S.
0
5
10
15
20
25
30
35
40
45
50
22
23
24
25


DISCHARGE - 1,000 C.F.S.
0
5
10
15
20
25
30
35
40
45
50
55
22
23

2







——— Actual

— — — — Regulated by existing reservoirs and projects under construction.

——— - ——— Regulated by water control plan.

REVIEW REPORT

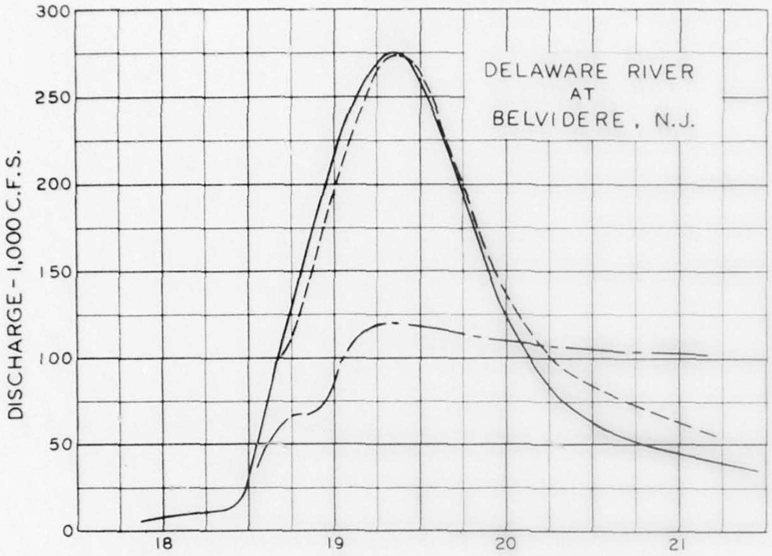
DELAWARE RIVER BASIN

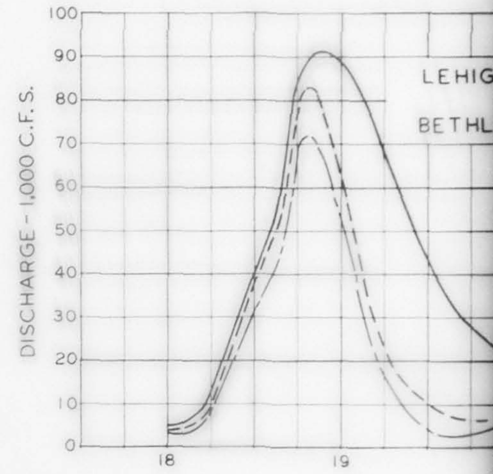
MODIFIED HYDROGRAPHS

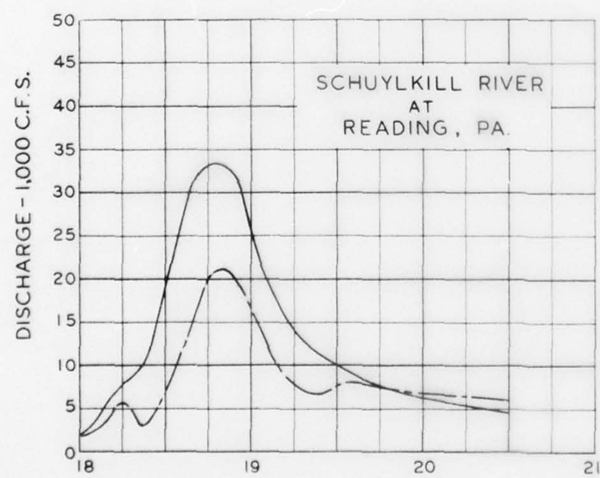
FLOOD OF MAY 1942

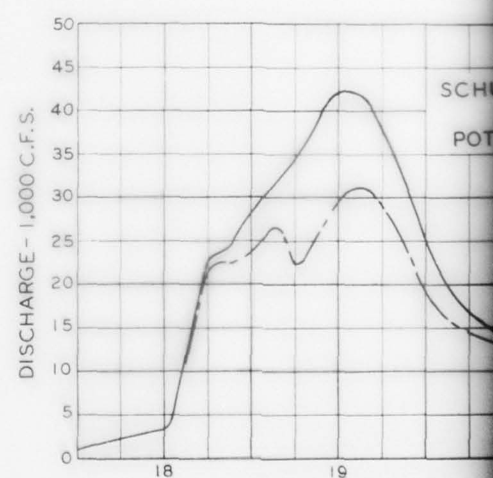
In 3 Sheets Sheet I Scales as Shown
Corps of Engineers Philadelphia District
Philadelphia, Pa. 23 Oct. 1959

Drawer No. 228 File No. 29048


DELAWARE RIVER
AT
BELVIDERE, N.J.
DISCHARGE - 1,000 C.F.S.
0
50
100
150
200
250
300
18
19
20
21

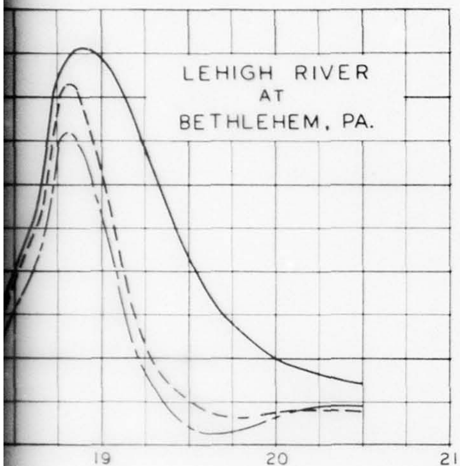

DISCHARGE - 1,000 C.F.S.
0
10
20
30
40
50
60
70
80
90
100
18
19

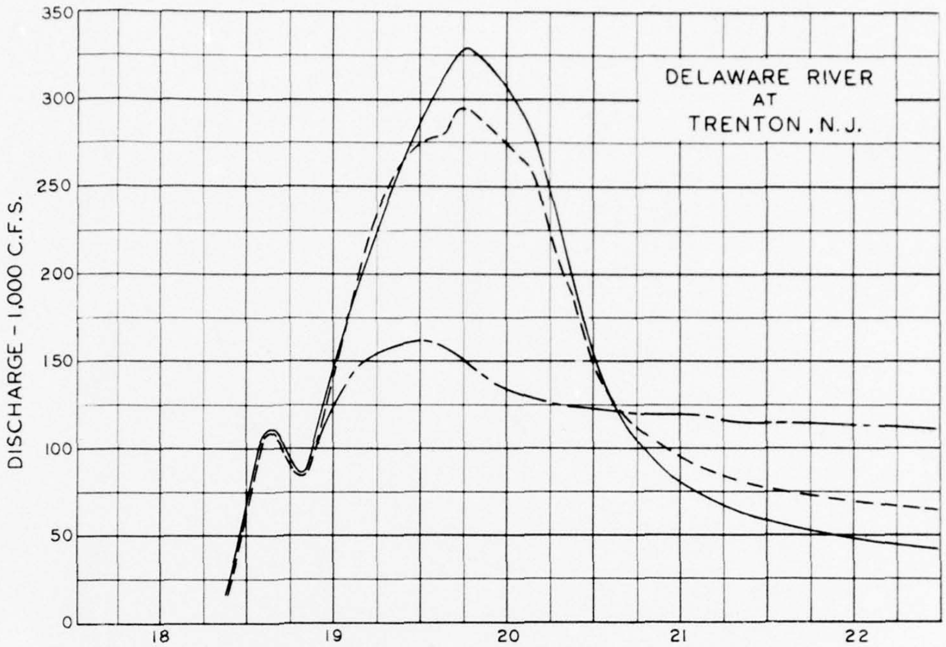

SCHUYLKILL RIVER
AT
READING, PA.
DISCHARGE - 1,000 C.F.S.
0
5
10
15
20
25
30
35
40
45
50
18
19
20
21

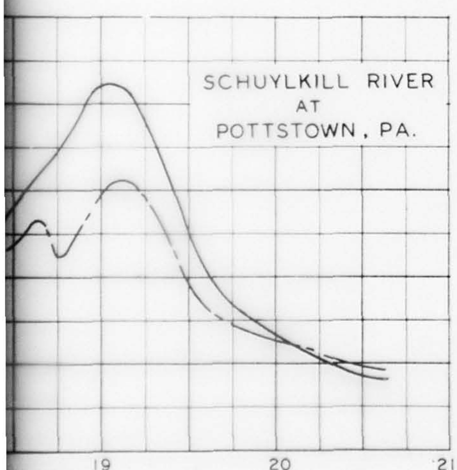

DISCHARGE - 1,000 C.F.S.
0
5
10
15
20
25
30
35
40
45
50
18
19

2

U. S. ARMY







——————— Actual

– – – – – – Regulated by existing reservoirs and projects under construction.

—— - —— Regulated by water control plan.

REVIEW REPORT

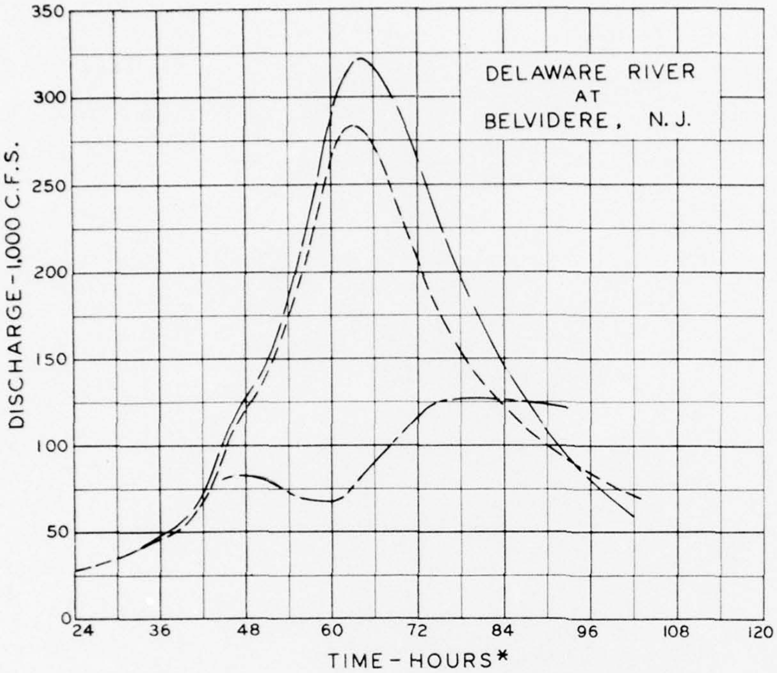
DELAWARE RIVER BASIN

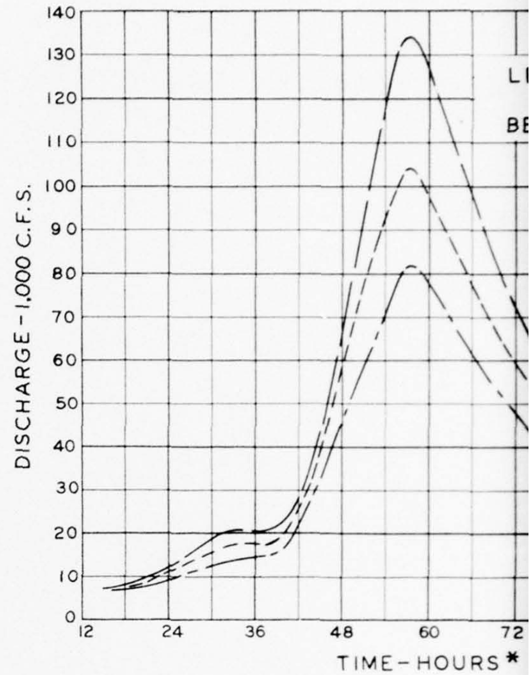
MODIFIED HYDROGRAPHS

FLOOD OF AUGUST 1955

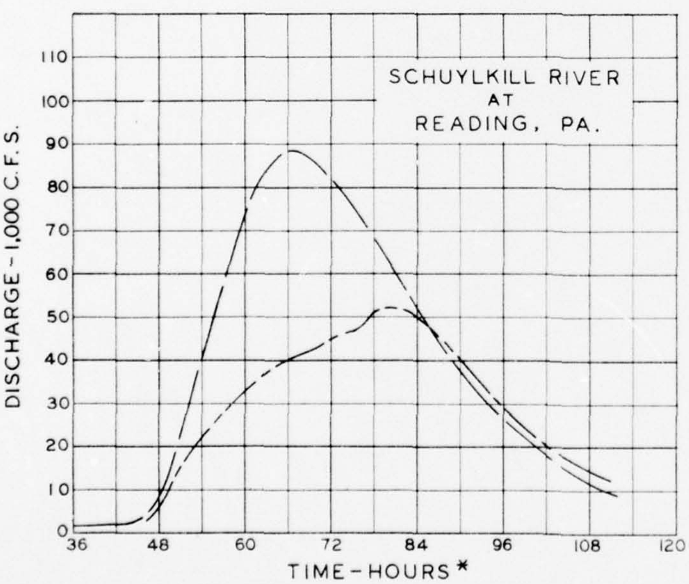
In 3 Sheets	Sheet 2	Scales as Shown
Corps of Engineers		Philadelphia District
Philadelphia, Pa.		23 Oct. 1959
Drawer No. 228		File No. 29049

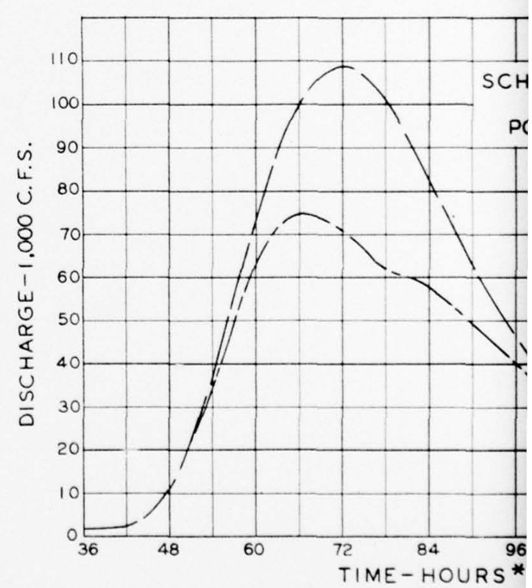
PLATE NO. 74





S T O R M OF M A Y 1 9

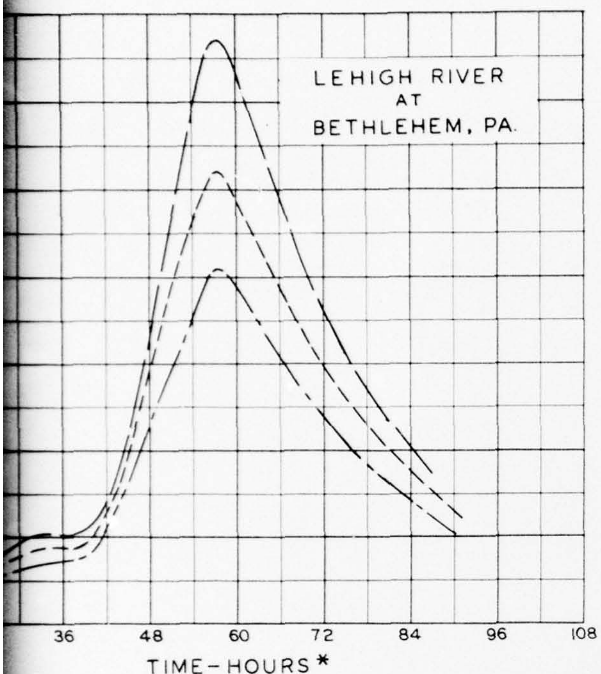


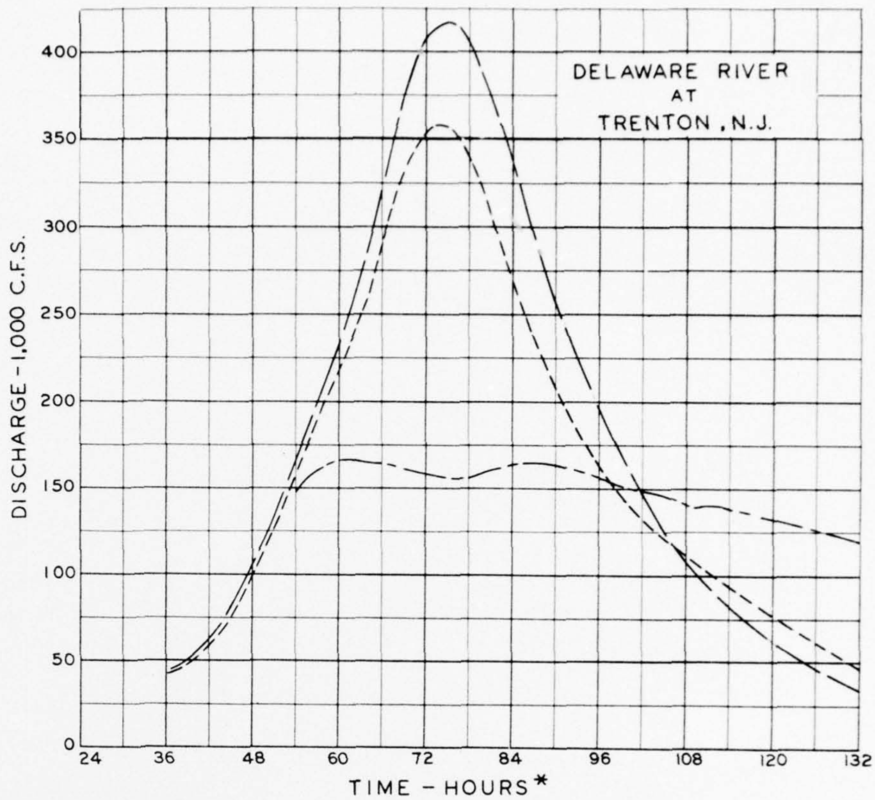


STORM OF AUGUST 1933 TRANSPOSED

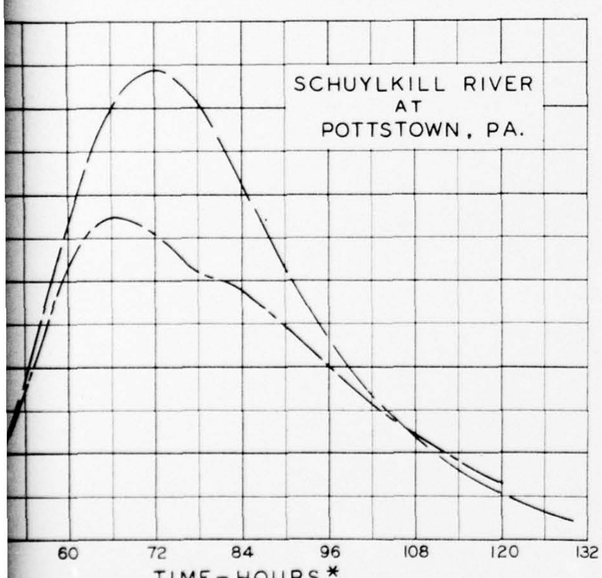
1

U. S. ARMY 2





M A Y 1 9 4 2 T R A N S P O S E D



RANSPOSED

Natural

Regulated by existing reservoirs
and projects under construction.

Regulated by water control plan.

* Time measured from start of rainfall.

REVIEW REPORT

DELAWARE RIVER BASIN

MODIFIED HYDROGRAPHS

BASIN PROJECT FLOODS

In 3 Sheets	Sheet 3	Scales as Shown
Corps of Engineers		Philadelphia District
Philadelphia, Pa.		23 Oct. 1959
Drawer No. 228		File No. 29050

PLATE NO. 75

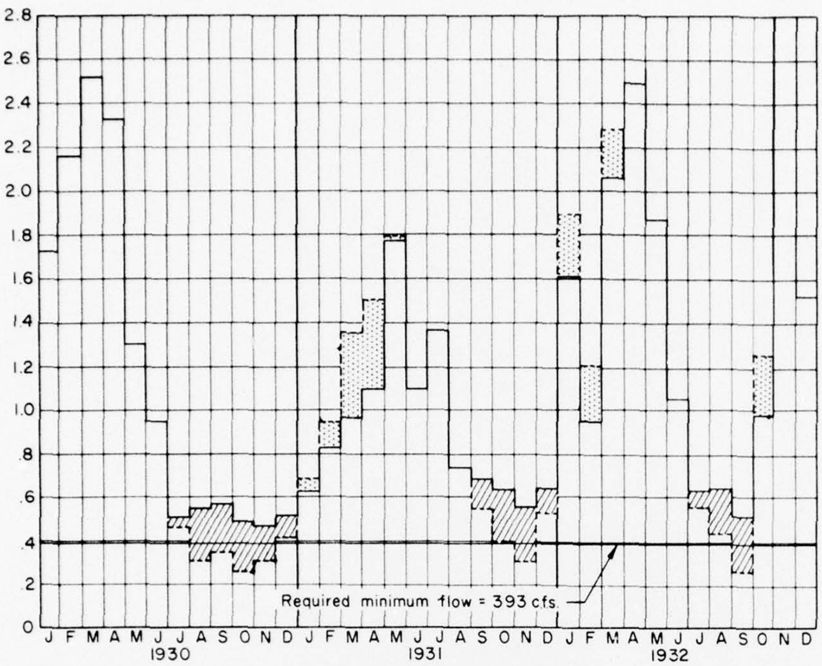


FIG. I SCHUYLKILL RIVER AT POTTSTOWN

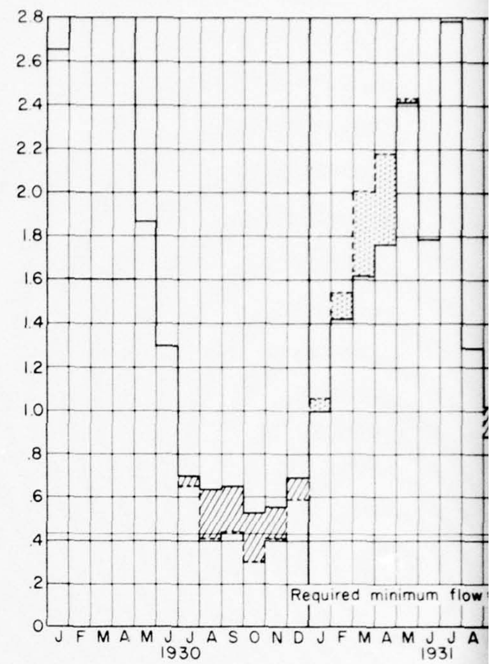


FIG. 2 SCHUYLKILL RIVER AT PHILADELP

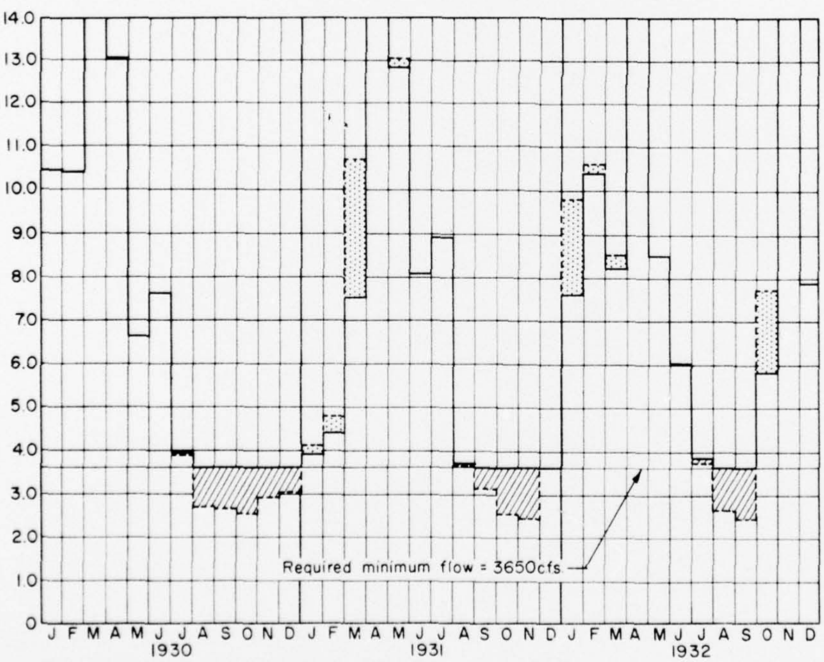


FIG. 4 DELAWARE RIVER AT TRENTON

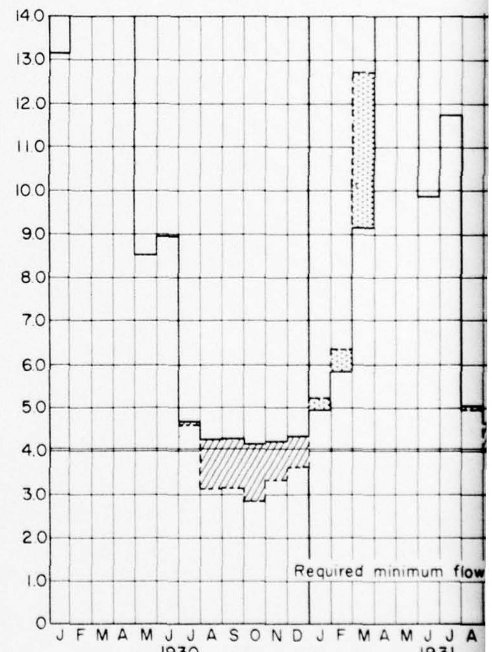
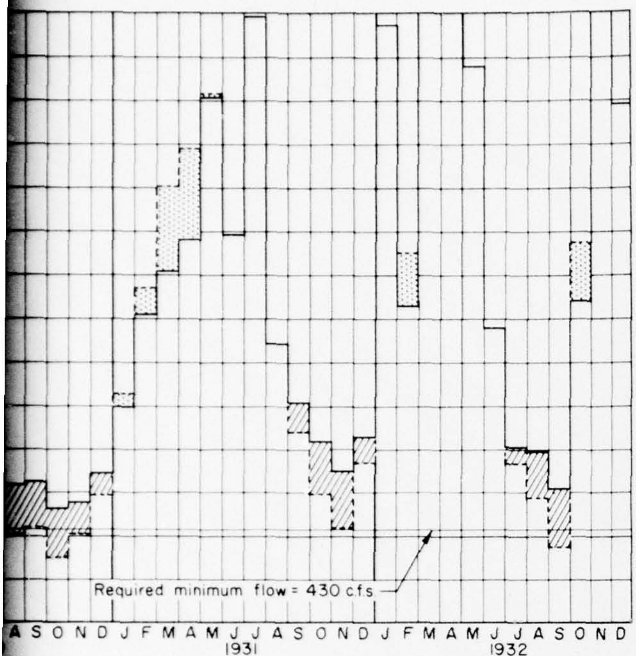


FIG. 5 DELAWARE R. AT TRENTON + SCHUY

2

U.S. ARMY



KILL RIVER AT PHILADELPHIA

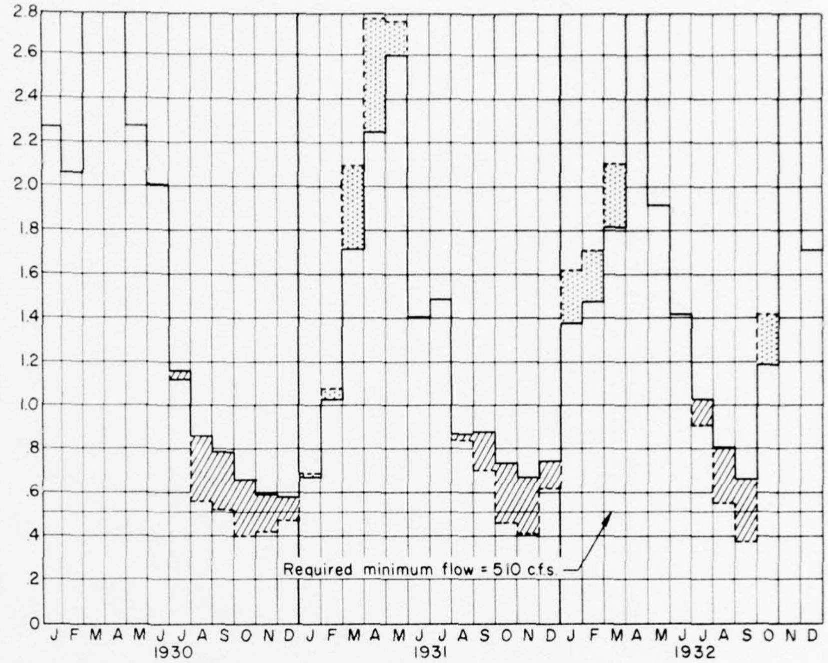


FIG. 3 LEHIGH RIVER AT BETHLEHEM

NOTES:

Flow augmentation by reservoir releases.

Flow reduction by storage in reservoirs.

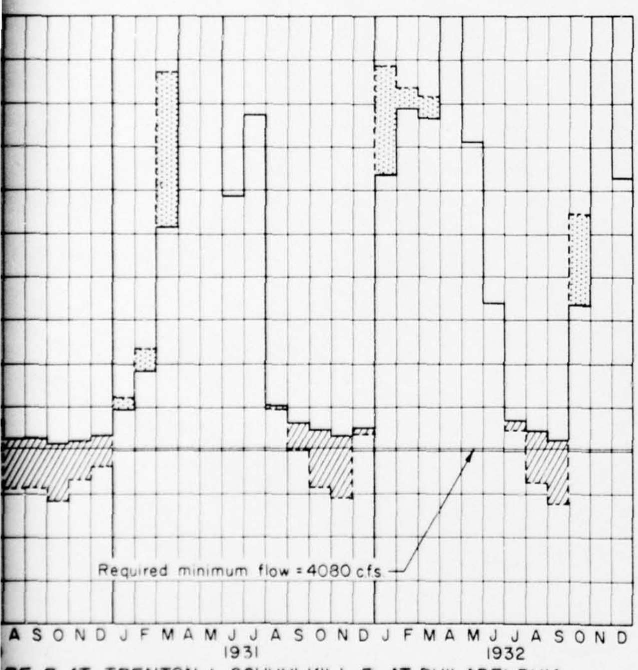
All vertical scales represent discharge in 1000 c.f.s.

Flows above 2,800 c.f.s. at Pottstown, Philadelphia and Bethlehem not shown.

Flows above 14,000 c.f.s. at Trenton and Trenton + Philadelphia not shown.

Minimum regulated flows equal or exceed 1988 low flow requirements in all cases.

Excess above required minimum flow for Trenton - Philadelphia area available for diversion to Wilmington and Northern New Jersey.



RE R. AT TRENTON + SCHUYLKILL R. AT PHILADELPHIA

REVIEW REPORT

DELAWARE RIVER BASIN

EFFECTS OF WATER CONTROL PLAN ON LOW FLOWS OF 1930-1932 AT YEAR 1988

In 1 Sheet | Scales as Shown

Corps of Engineers | Philadelphia District

Philadelphia, Pa. | 6 May 1960

Drawer No. 228 | File No. 29076

PLATE NO. 76

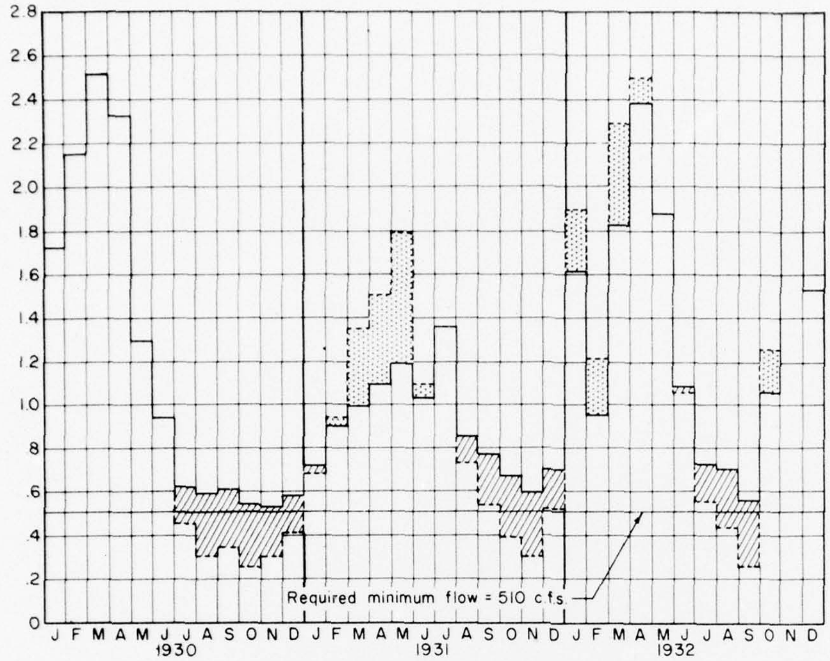


FIG. 1 SCHUYLKILL RIVER AT POTTSTOWN

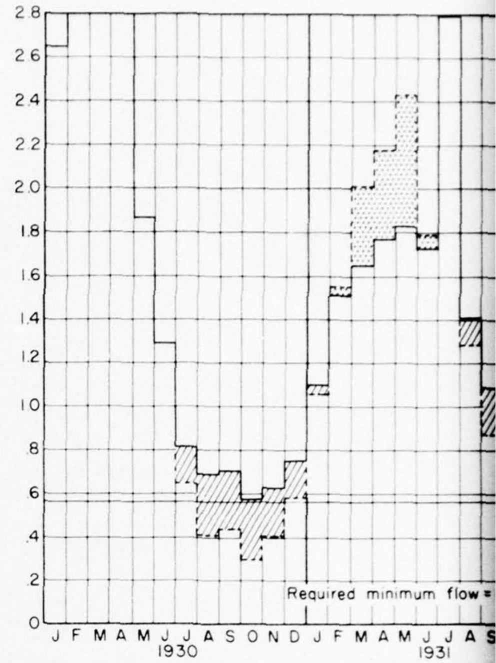


FIG. 2 SCHUYLKILL RIVER AT PHILADELPI

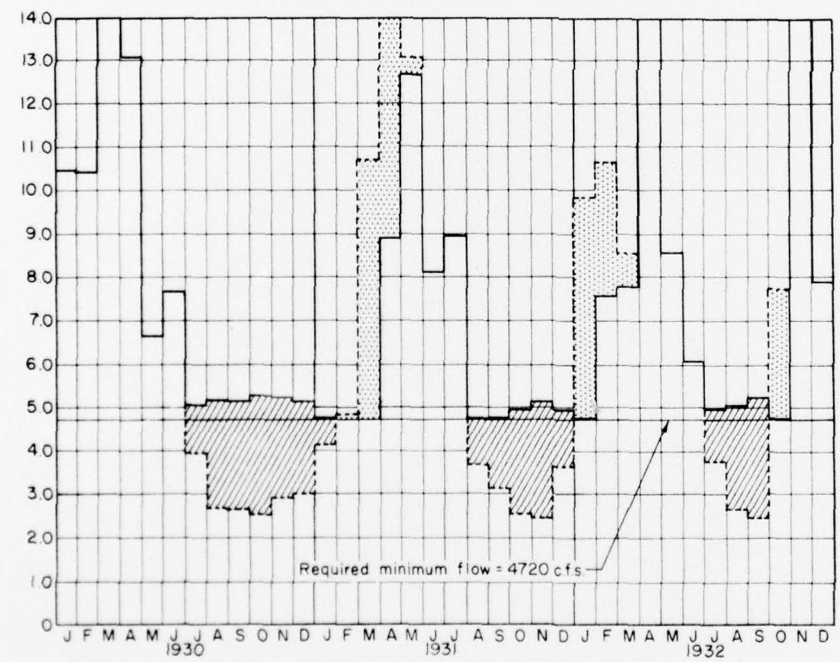


FIG. 4 DELAWARE RIVER AT TRENTON

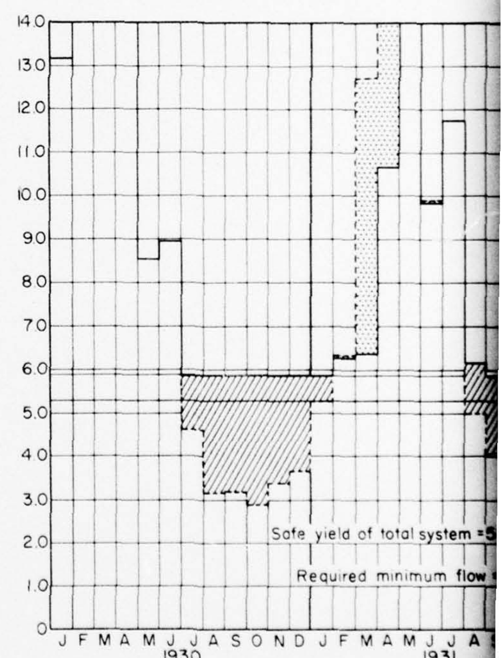
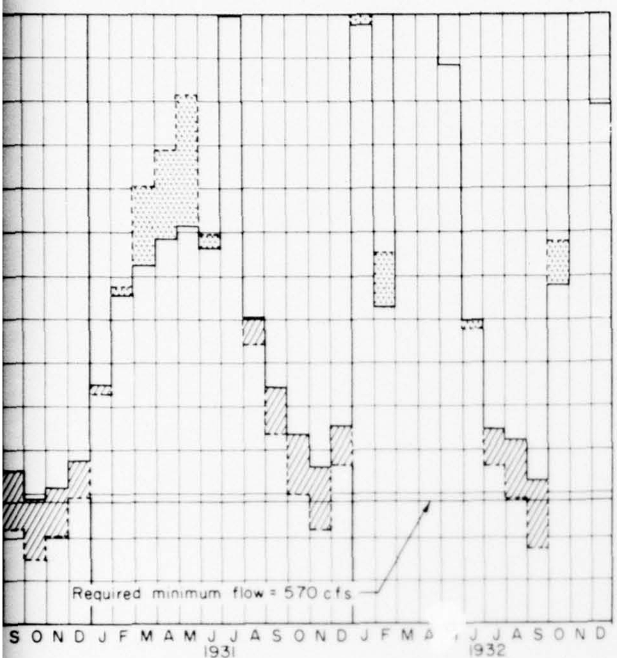


FIG. 5 DELAWARE RIVER AT TRENTON +

2

U.S. ARMY



LL RIVER AT PHILADELPHIA

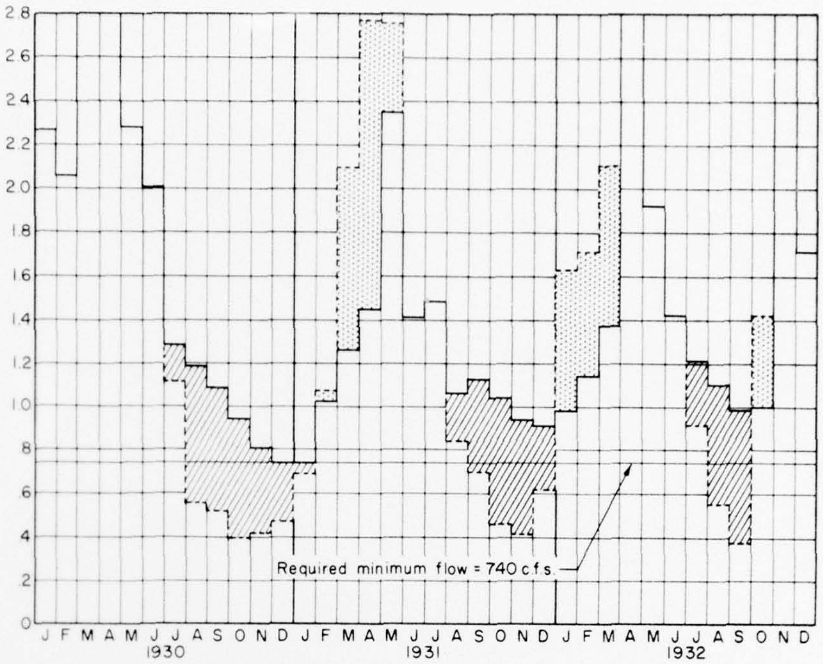


FIG. 3 LEHIGH RIVER AT BETHLEHEM

NOTES:

Flow augmentation by reservoir releases.

Flow reduction by storage in reservoirs.

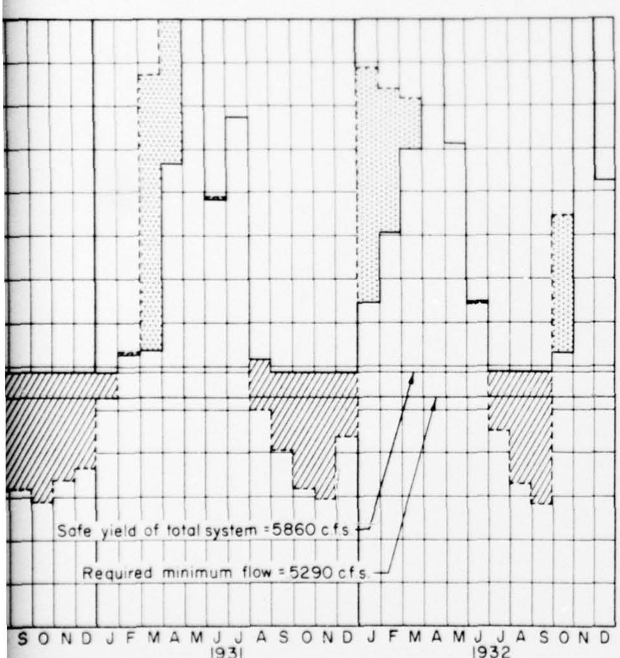
All vertical scales represent discharge in 1000 c.f.s.

Flows above 2,800 c.f.s. at Pottstown, Philadelphia and Bethlehem not shown.

Flows above 14,000 c.f.s. at Trenton and Trenton + Philadelphia not shown.

Minimum regulated flows equal or exceed 2010 low flow requirements in all cases.

Excess above required minimum flow for Trenton - Philadelphia area available for diversion to Wilmington and Northern New Jersey.



E RIVER AT TRENTON + PHILADELPHIA

REVIEW REPORT

DELAWARE RIVER BASIN

EFFECTS OF WATER CONTROL PLAN ON LOW FLOWS OF 1930-1932 AT YEAR 2010

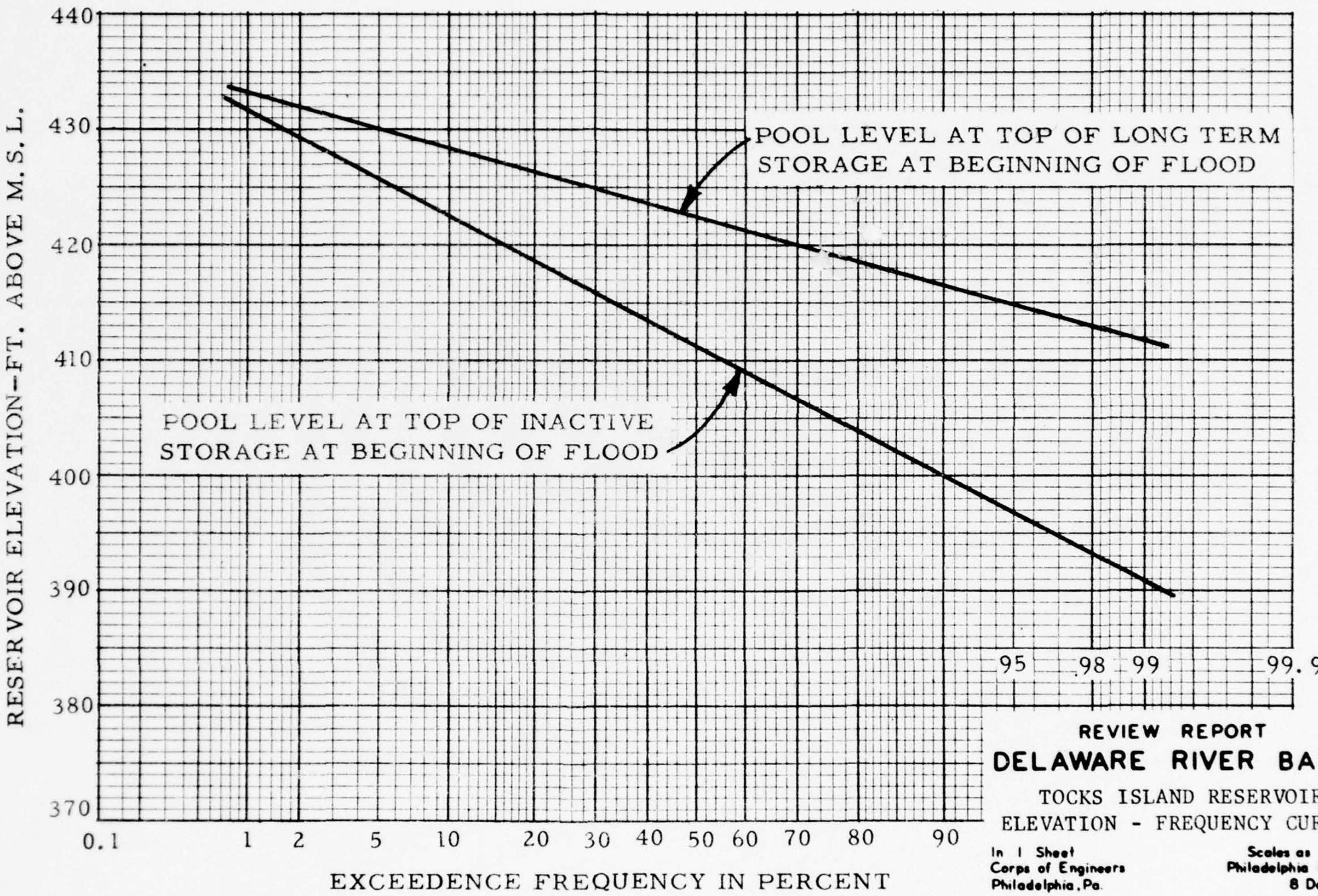
In 1 Sheet | Scales as Shown
Corps of Engineers | Philadelphia District
Philadelphia, Pa. | 6 May 1960

Drawer No. 228 | File No. 29077

PLATE NO. 77

CORPS OF ENGINEERS

U. S. ARMY



REVIEW REPORT

DELAWARE RIVER BASIN

TOCKS ISLAND RESERVOIR

ELEVATION - FREQUENCY CURVES

In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scales as Shown
Philadelphia District
8 Dec. 1959

Drawer No. 228

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PLATE NO. 78

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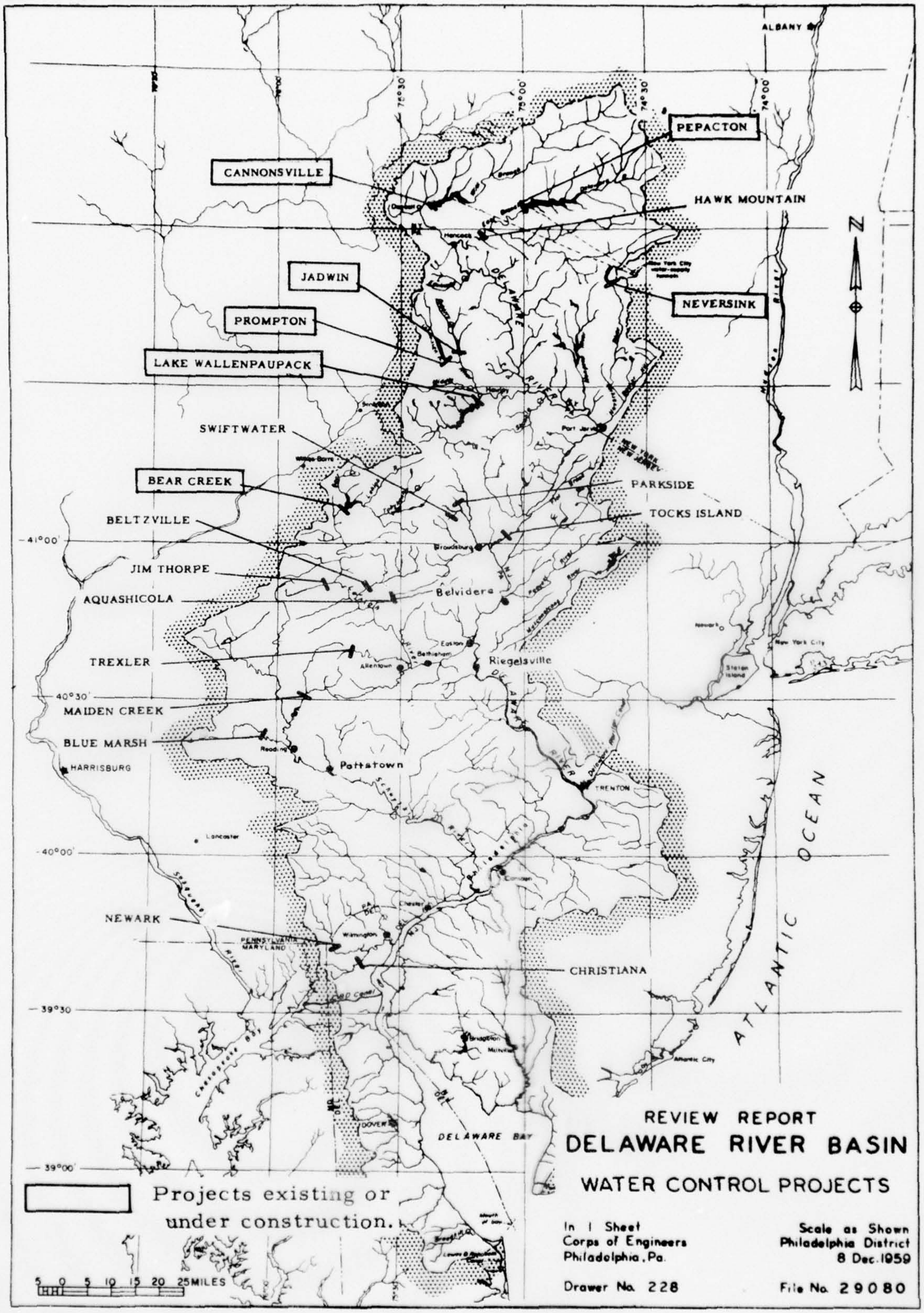

REVIEW REPORT

DELAWARE RIVER BASIN

WATER CONTROL PROJECTS

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